US011415399B1

(12) United States Patent
Beckett et al.

(10) Patent No.: US 11,415,399 B1
(45) Date of Patent: Aug. 16, 2022

(54) **IGNITION APPARATUS FOR PROJECTILE**

(71) Applicant: **The United States of America as Represented by the Secretary of the Navy**, Indian Head, MD (US)

(72) Inventors: **Kyle Matthew Beckett**, Leonardtown, MD (US); **Earle Monroe Sparks**, Ridgely, MD (US); **Xavier Omar Velez-Ocasio**, King George, VA (US); **David Reinaldo Gonzalez**, King George, VA (US); **Greg Young**, Blacksburg, VA (US)

(73) Assignee: **The United States of America as represented by the Secretary of the Navy**, Washington, DC (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 57 days.

(21) Appl. No.: **16/974,274**

(22) Filed: **Dec. 15, 2020**

(51) **Int. Cl.**
F42C 15/24 (2006.01)
F42C 15/20 (2006.01)

(52) **U.S. Cl.**
CPC ***F42C 15/24*** (2013.01); ***F42C 15/20*** (2013.01)

(58) **Field of Classification Search**
CPC F42C 1/02–06; F42C 14/00; F42C 15/16; F42C 15/20; F42C 15/24; F42C 15/26
USPC 102/216, 247, 251, 252
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,417,498 A 11/1983 Dissmyer et al.
4,557,198 A * 12/1985 Hickey F42B 12/58 102/489
6,321,654 B1 * 11/2001 Robinson F42C 15/24 102/251
6,851,348 B1 2/2005 Ang
7,779,740 B1 8/2010 Holmes et al.
8,061,271 B2 11/2011 Murray et al.
8,833,261 B1 9/2014 Thorniley et al.
10,386,144 B1 8/2019 Facteau et al.
2007/0295233 A1 * 12/2007 Karmazyn F42C 15/40 102/251
2008/0011179 A1 * 1/2008 Michel F42C 1/04 102/254
2008/0110365 A1 5/2008 Rasteghar et al.
2010/0031841 A1 * 2/2010 Michel F42C 15/184 102/222
2021/0095942 A1 * 4/2021 Koehler F42C 15/36

FOREIGN PATENT DOCUMENTS

GB 2006401 A * 5/1979 .... F42C 1/02

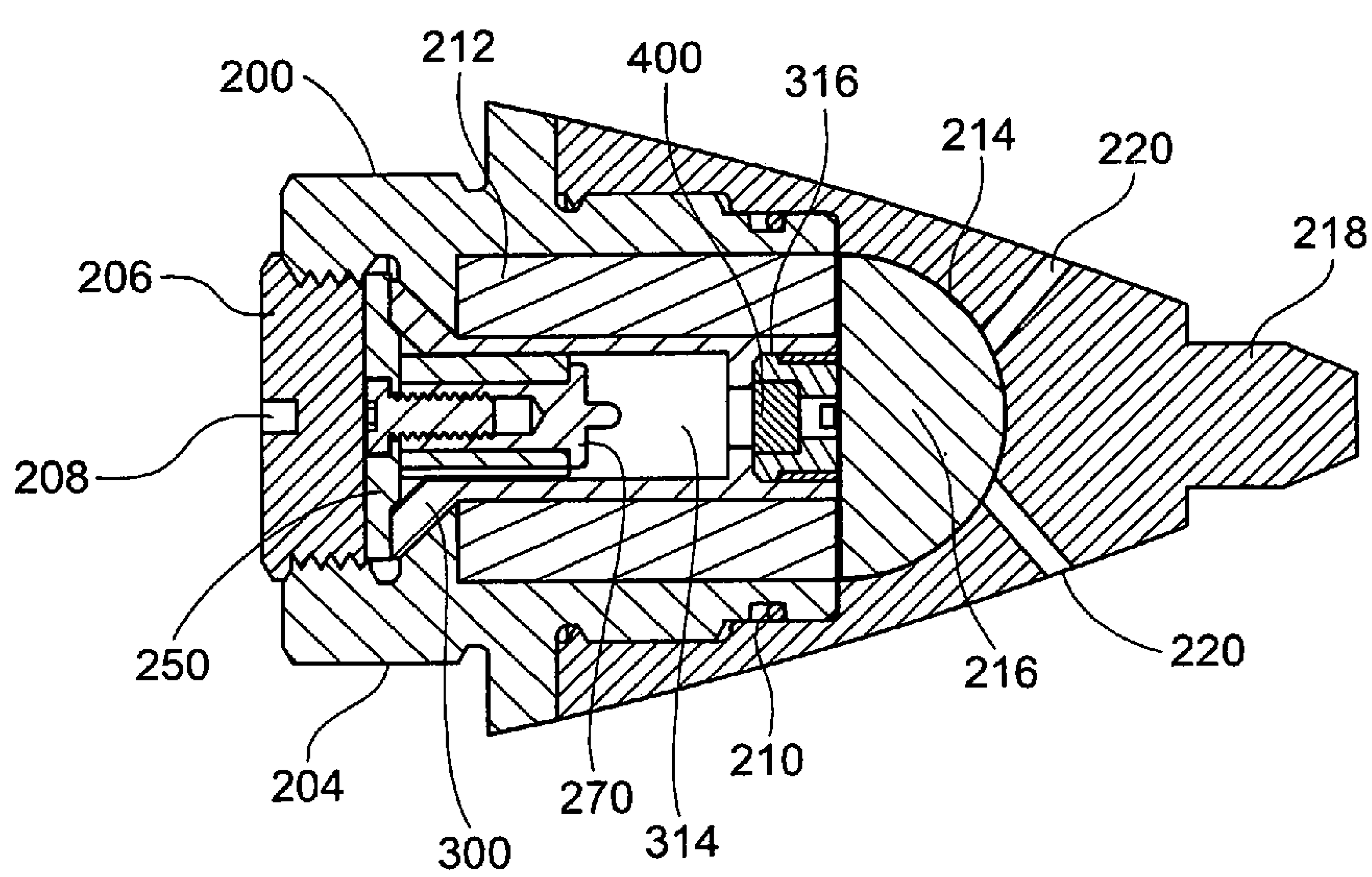
* cited by examiner

Primary Examiner — Bret Hayes
(74) *Attorney, Agent, or Firm* — Fredric J. Zimmerman

(57) **ABSTRACT**

Exemplary embodiments of an ignition apparatus are disclosed herein. Each ignition apparatus is configured for use in a projectile, such as an artillery projectile, rocket, missile, drone, and other similar projectiles. In each exemplary embodiment disclosed herein, the ignition apparatus initiates an ignition sequence that is the reverse of the ignition sequences implemented by conventional ignition devices that utilize pre-loaded or pre-compressed spring-operated firing pins. Each exemplary embodiment of the ignition apparatus disclosed herein utilizes the extreme axial acceleration of the projectile to arm and initiate the ignition sequence.

20 Claims, 13 Drawing Sheets



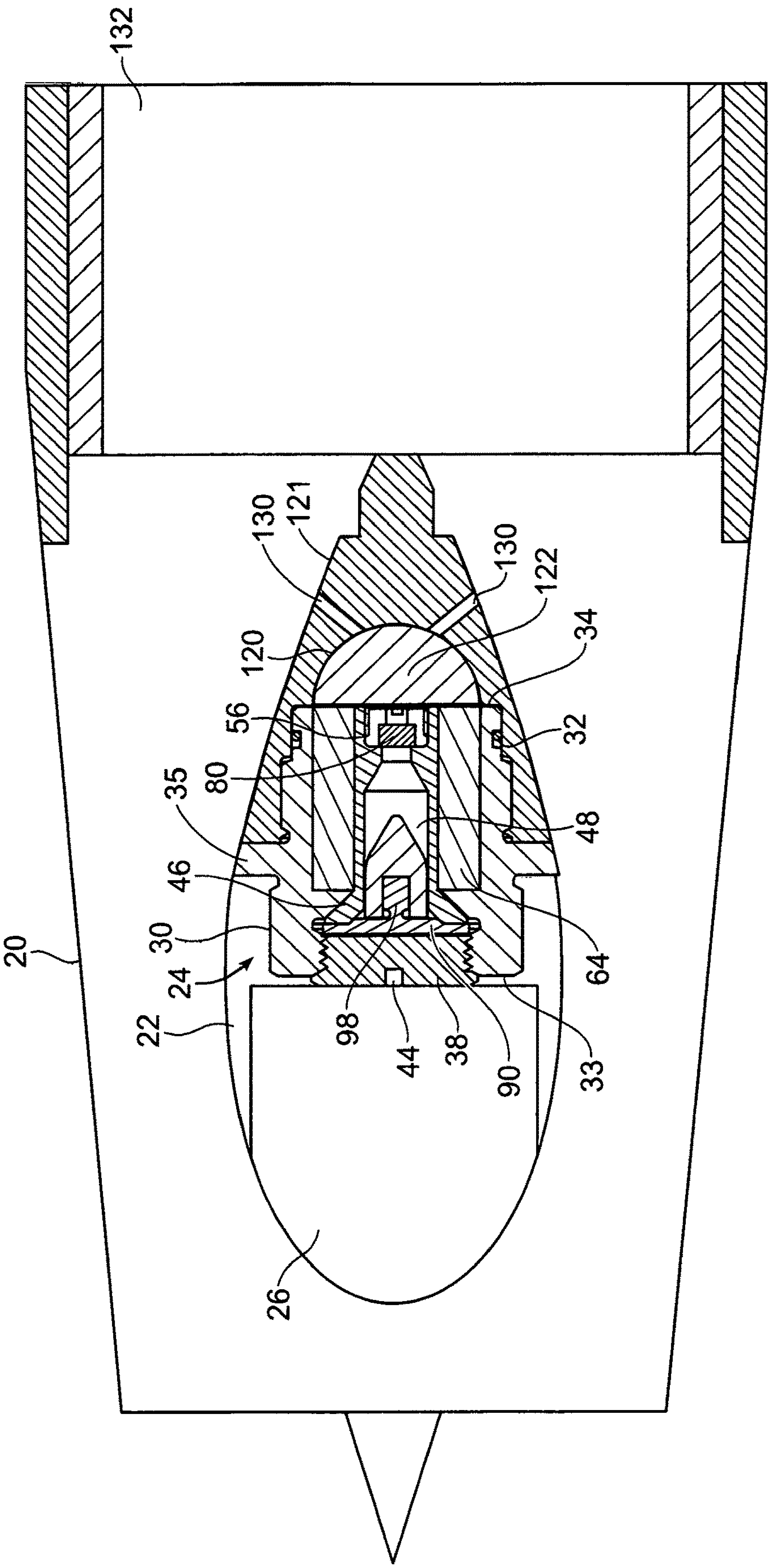

132
130
121
130
122
120
34
56
32
80
35
48
46
30
64
20
24
22
98
44
38
90
33
26

FIG. 1

FIG. 2

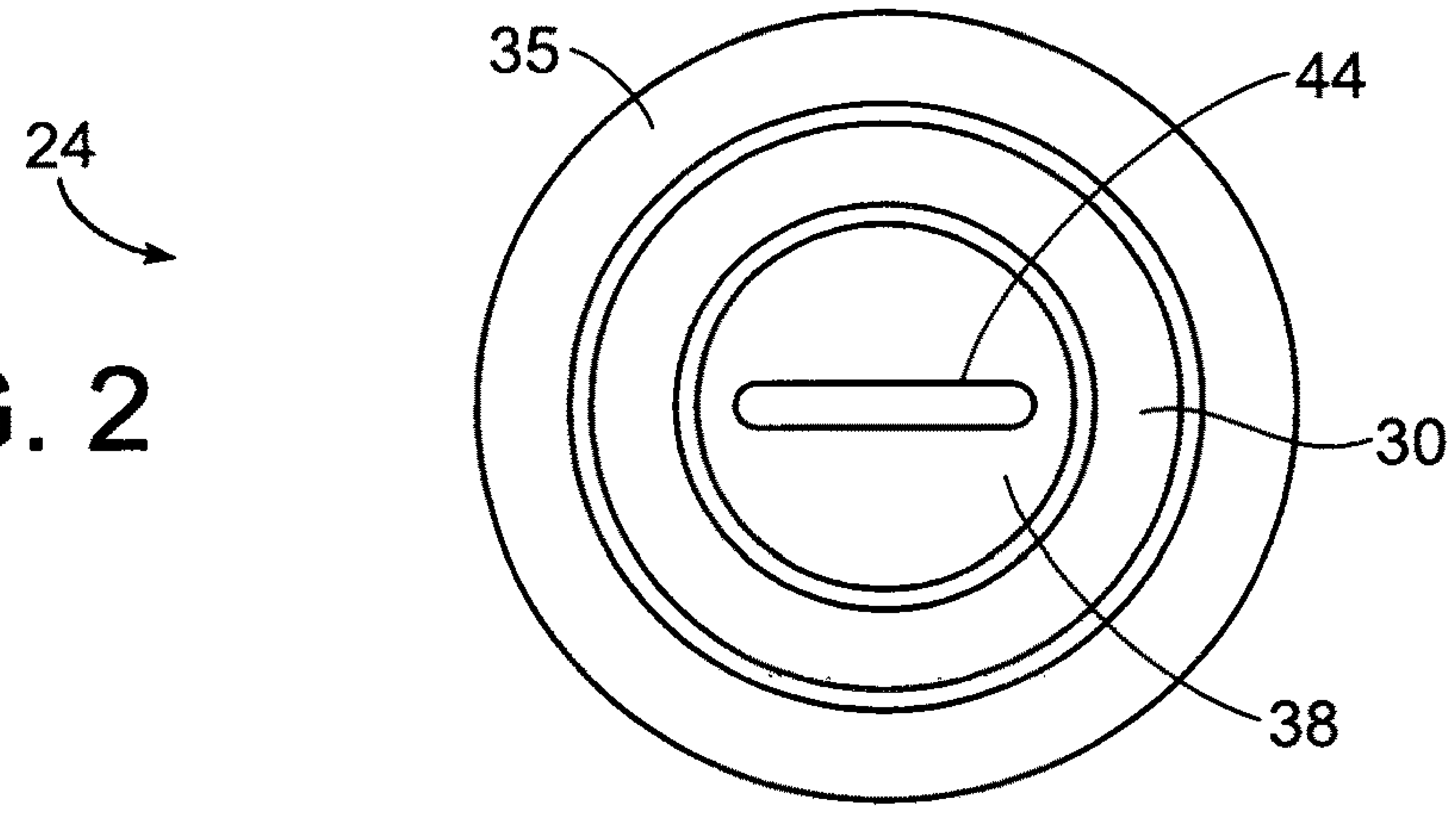


FIG. 3

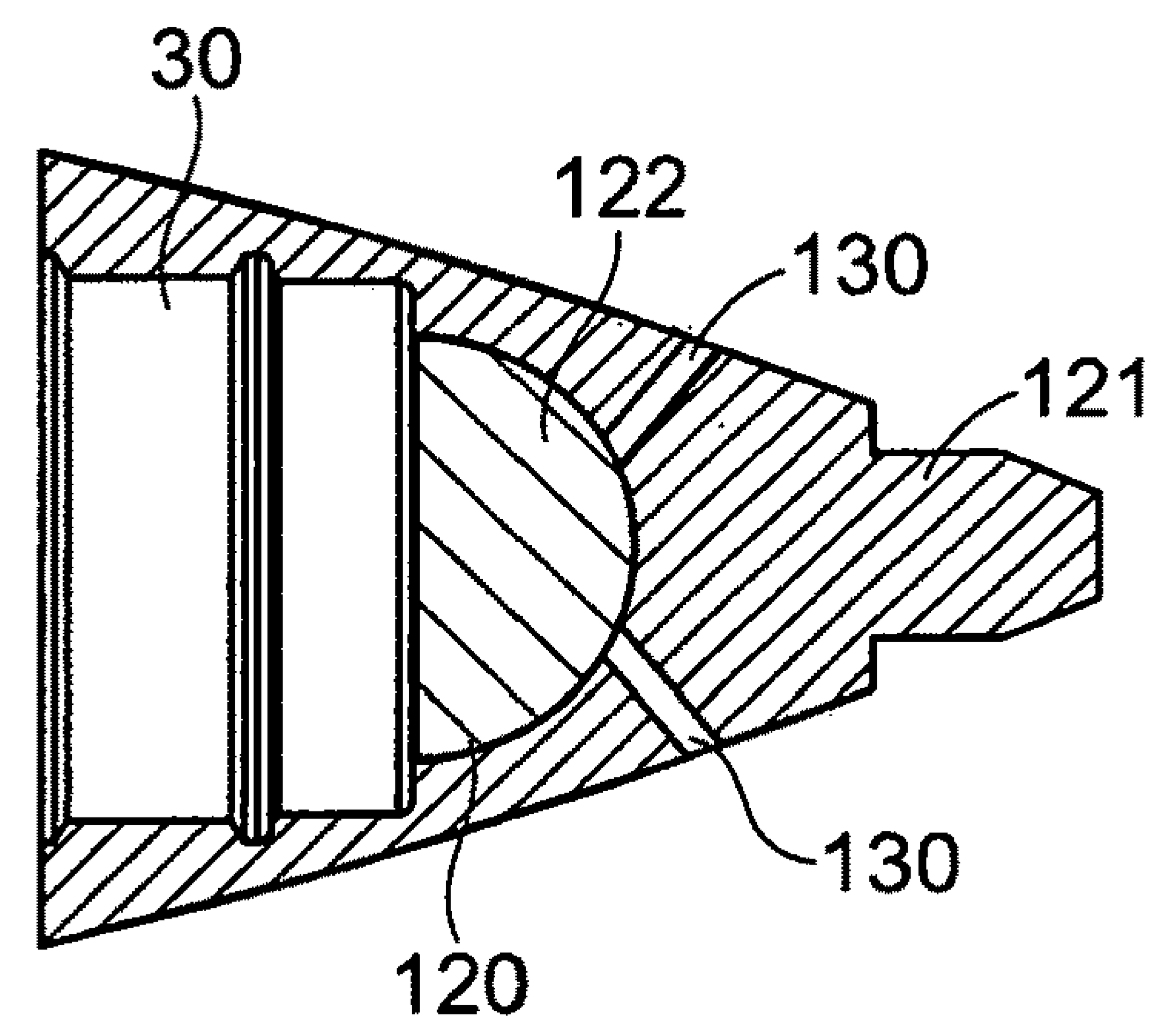
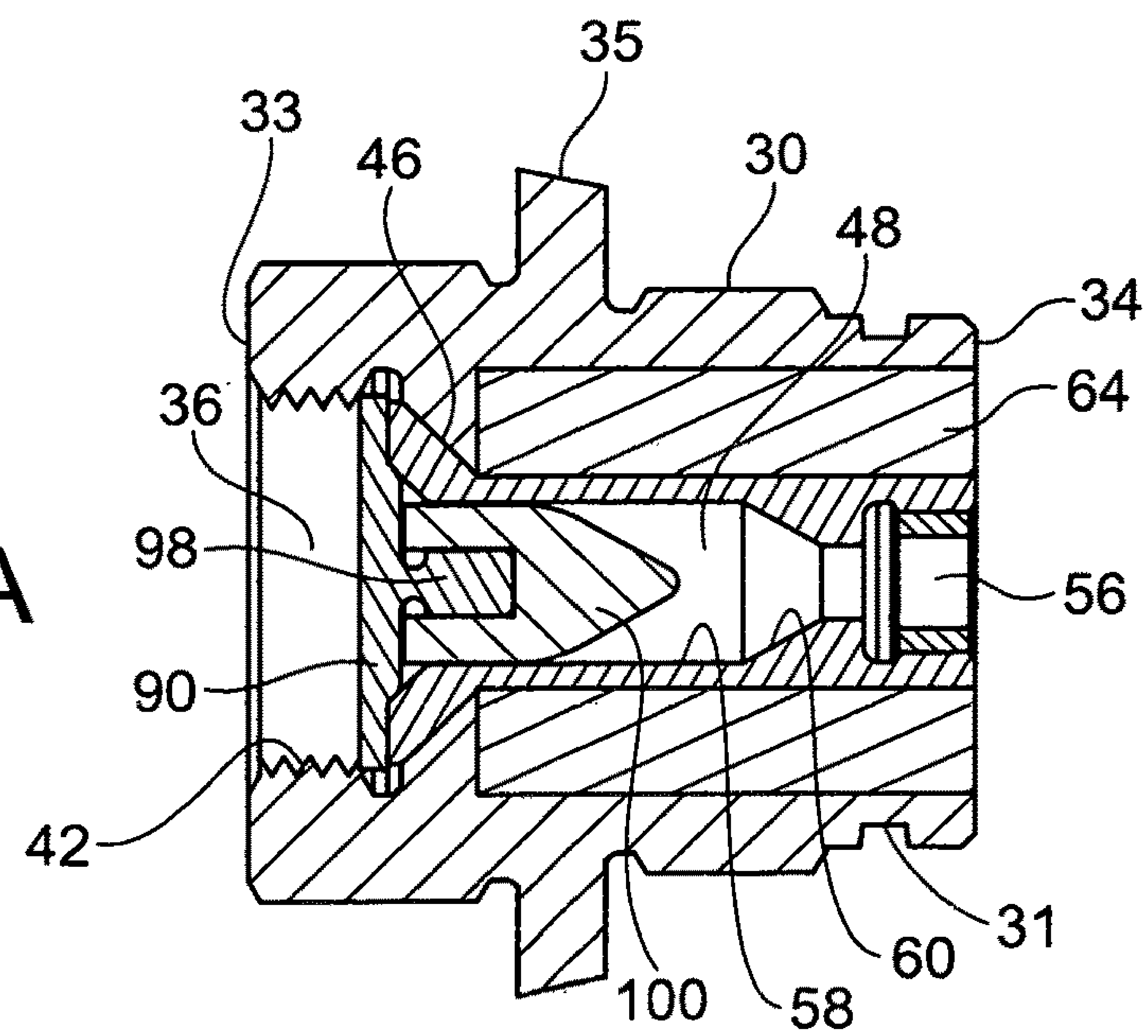


FIG. 4A



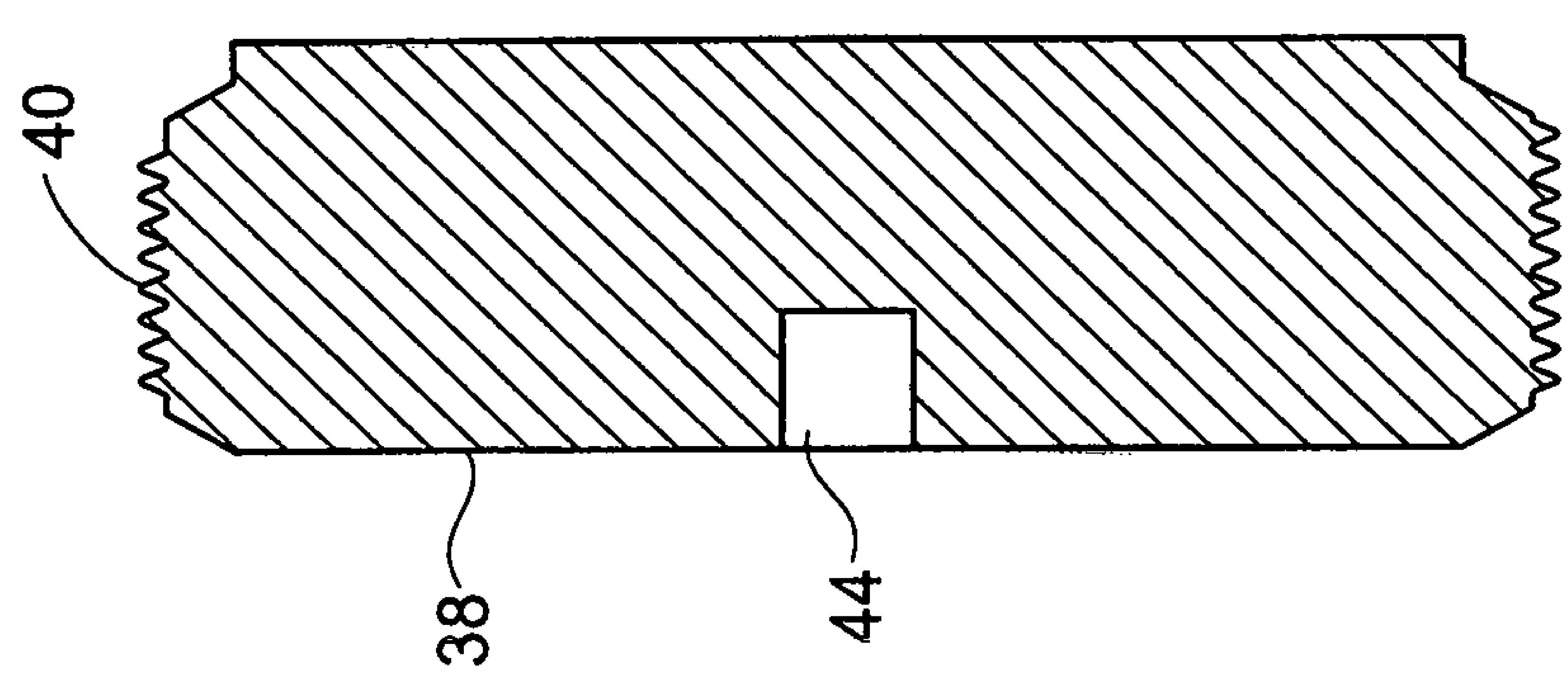


FIG. 4C

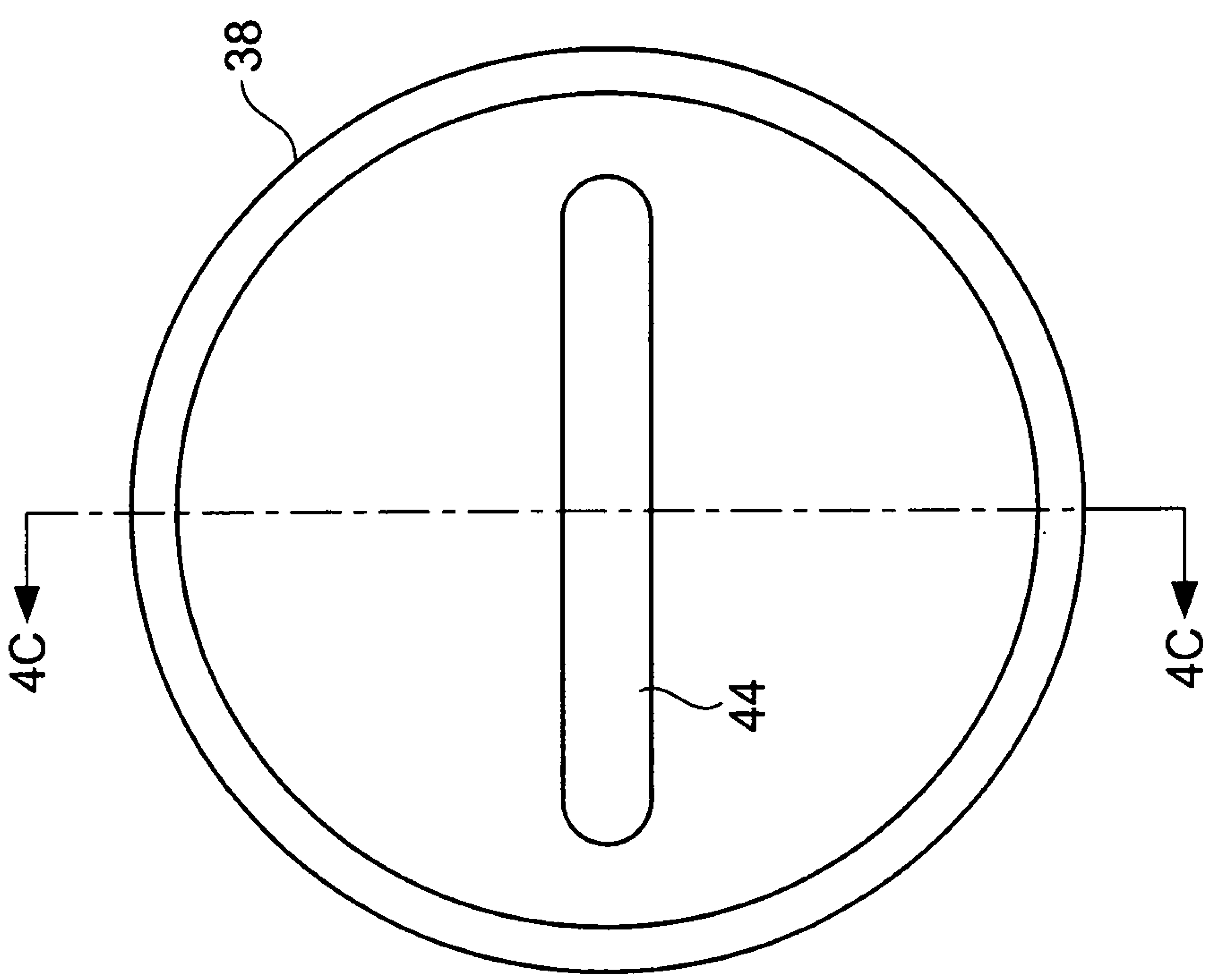


FIG. 4B

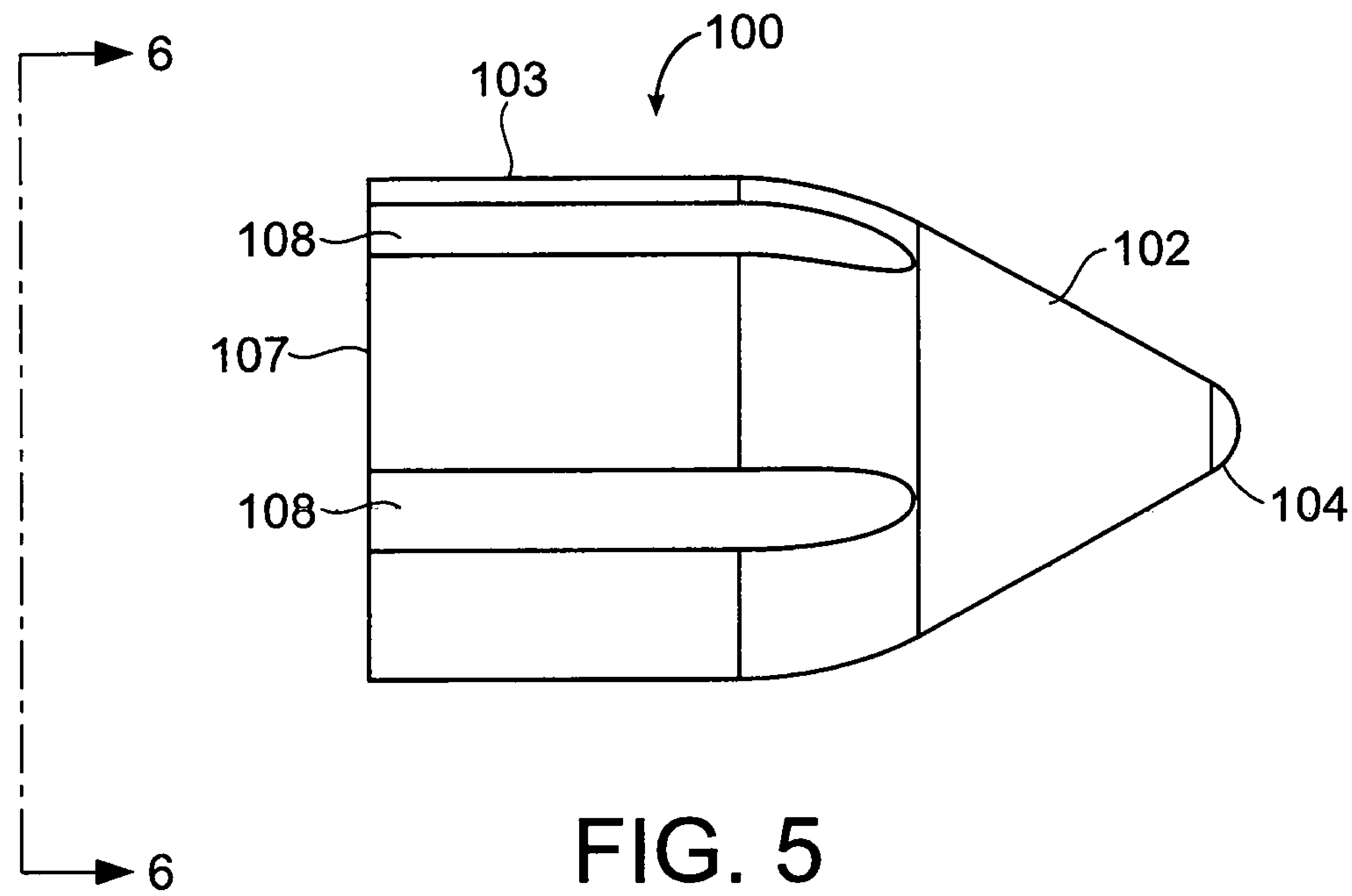


FIG. 5

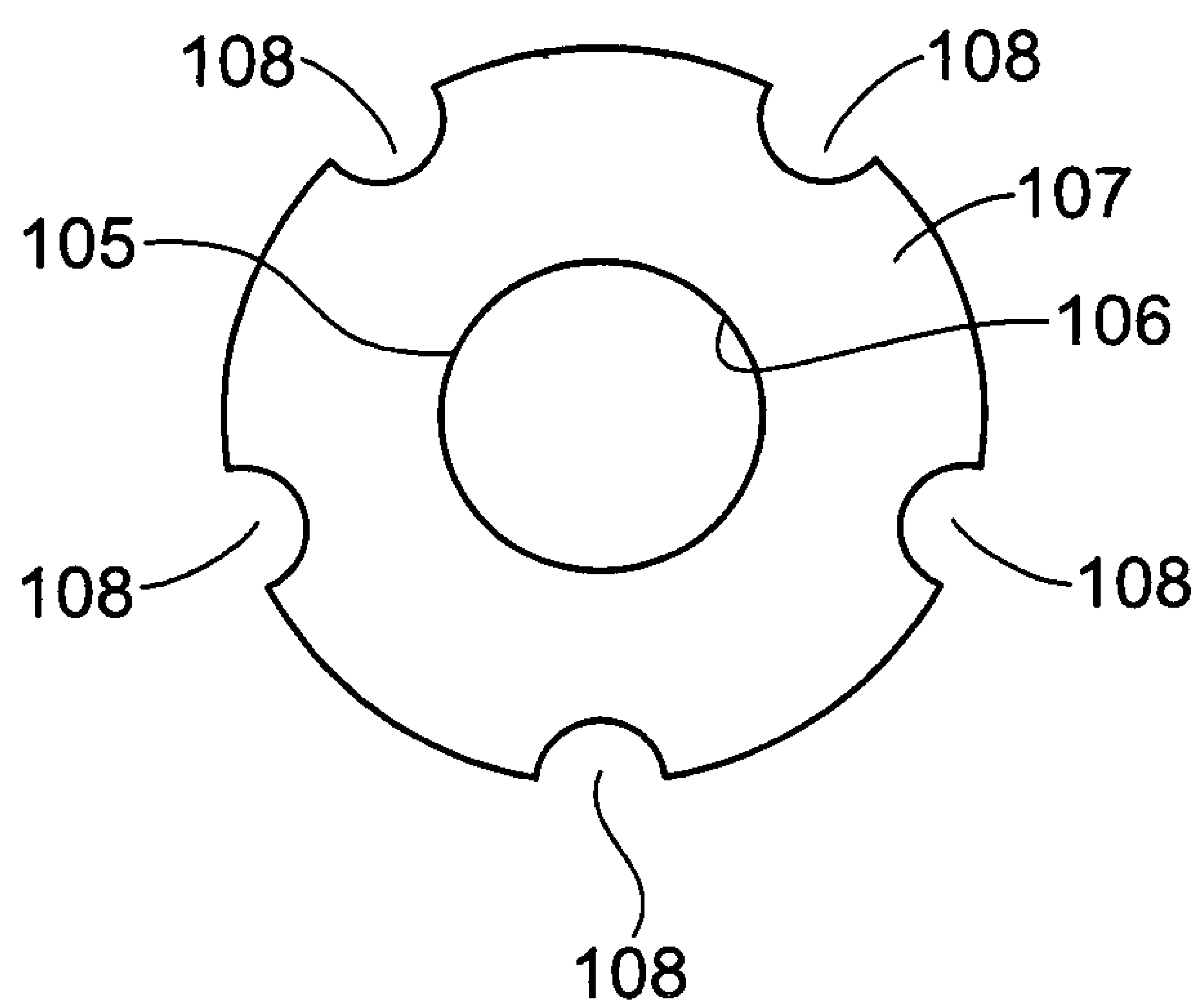


FIG. 6

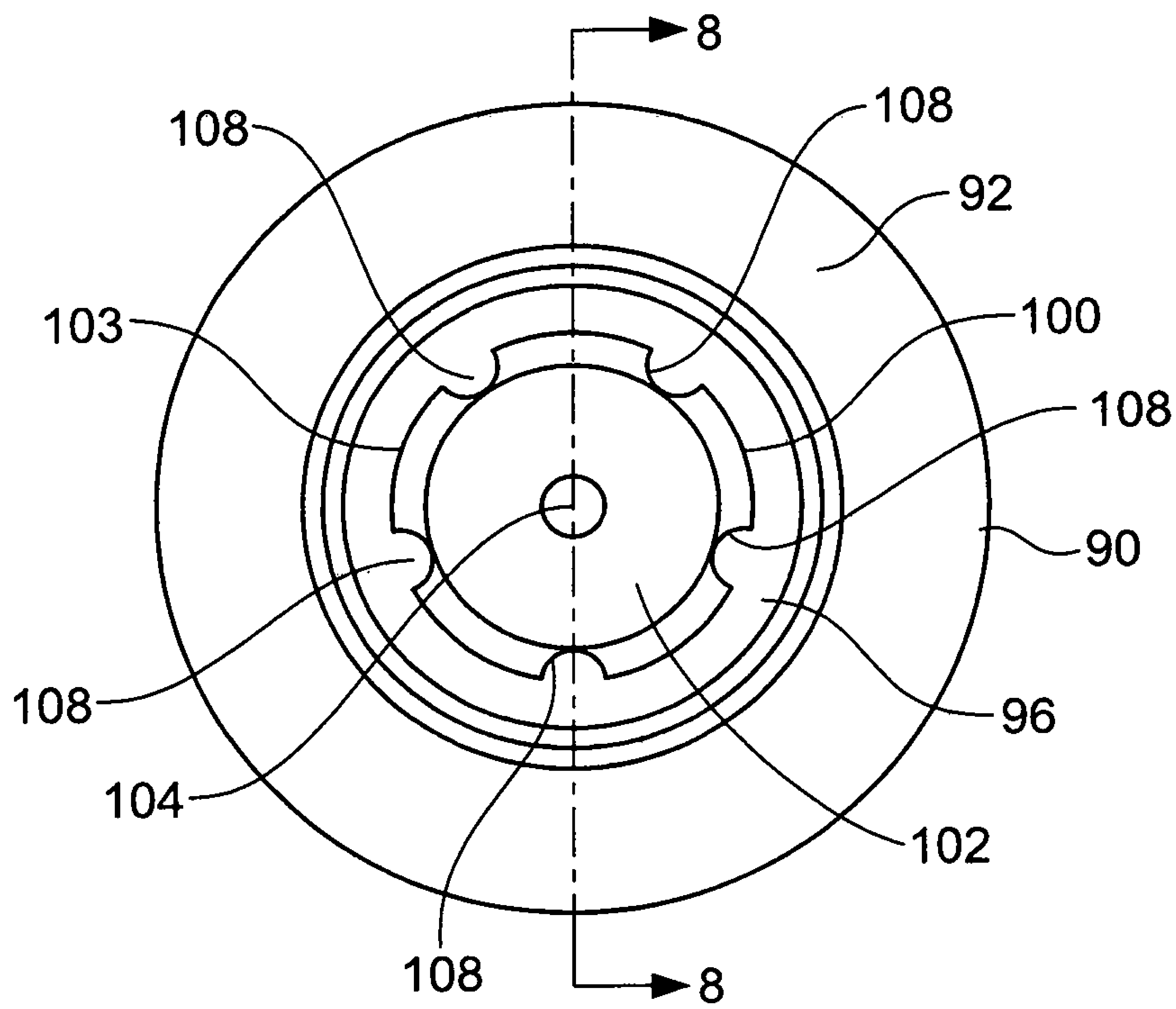

8
108
108
92
103
100
108
90
108
96
104
102
108
8

FIG. 7

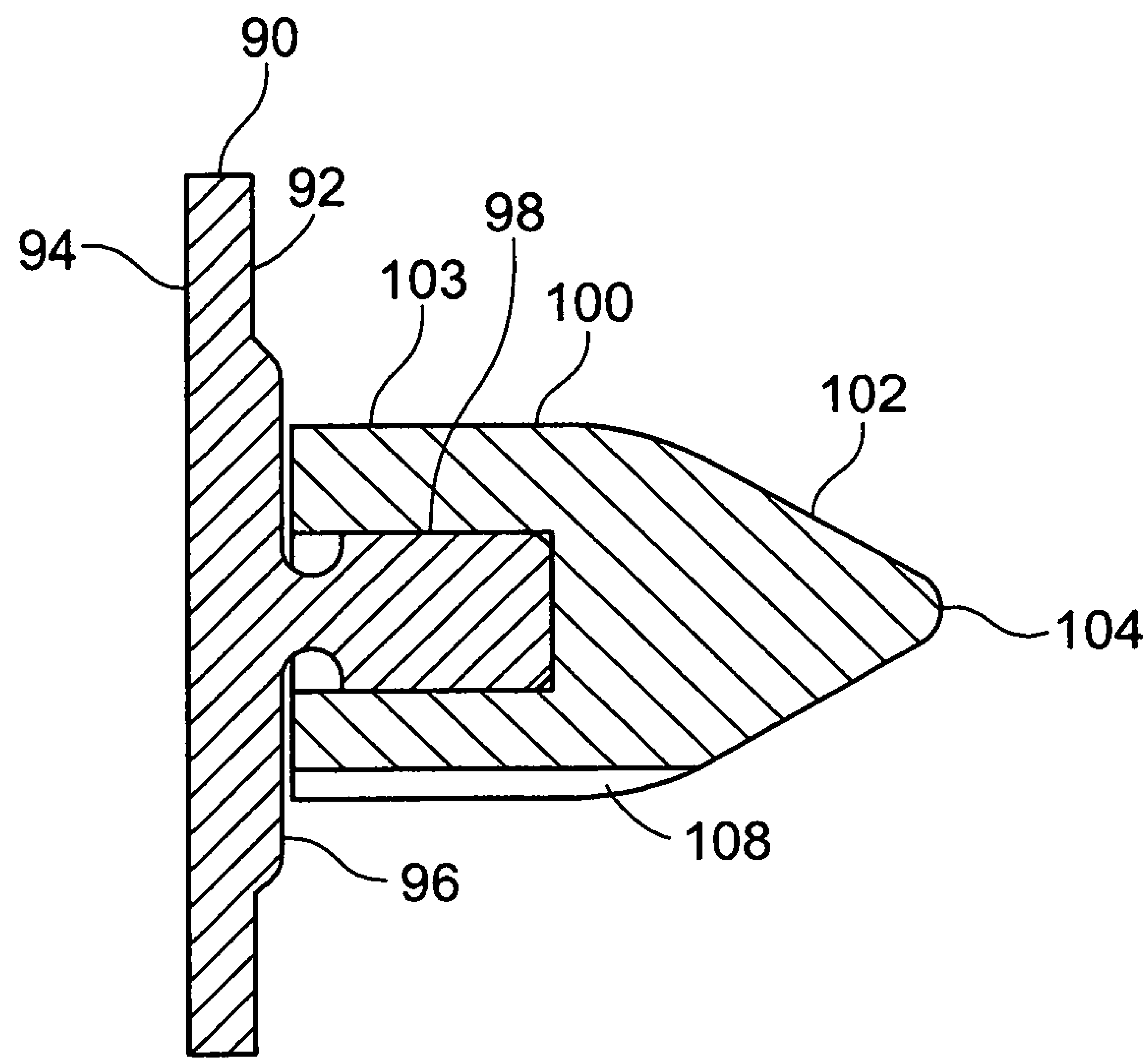

90
92
94
98
103
100
102
104
108
96

FIG. 8

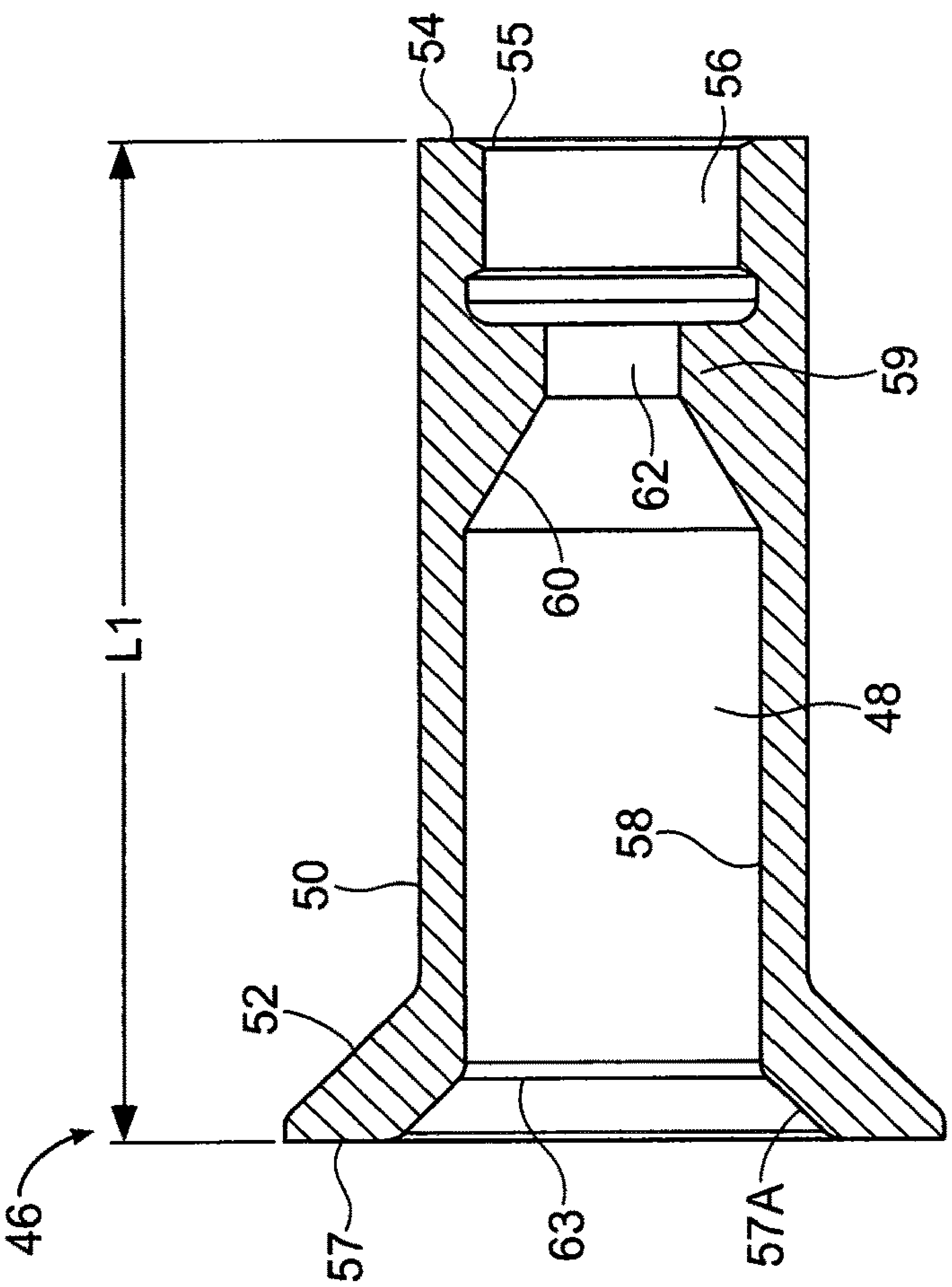


FIG. 10

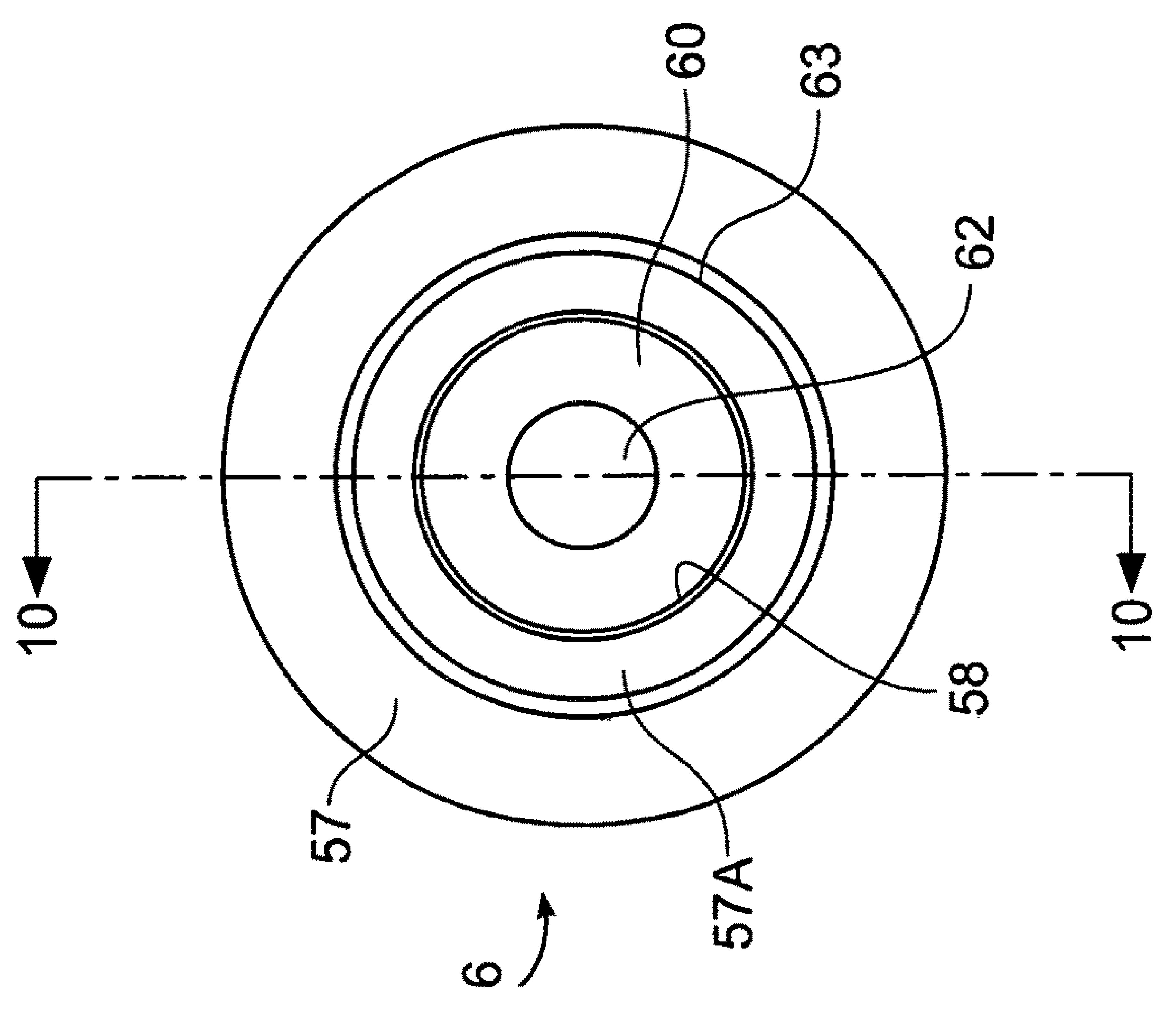


FIG. 9

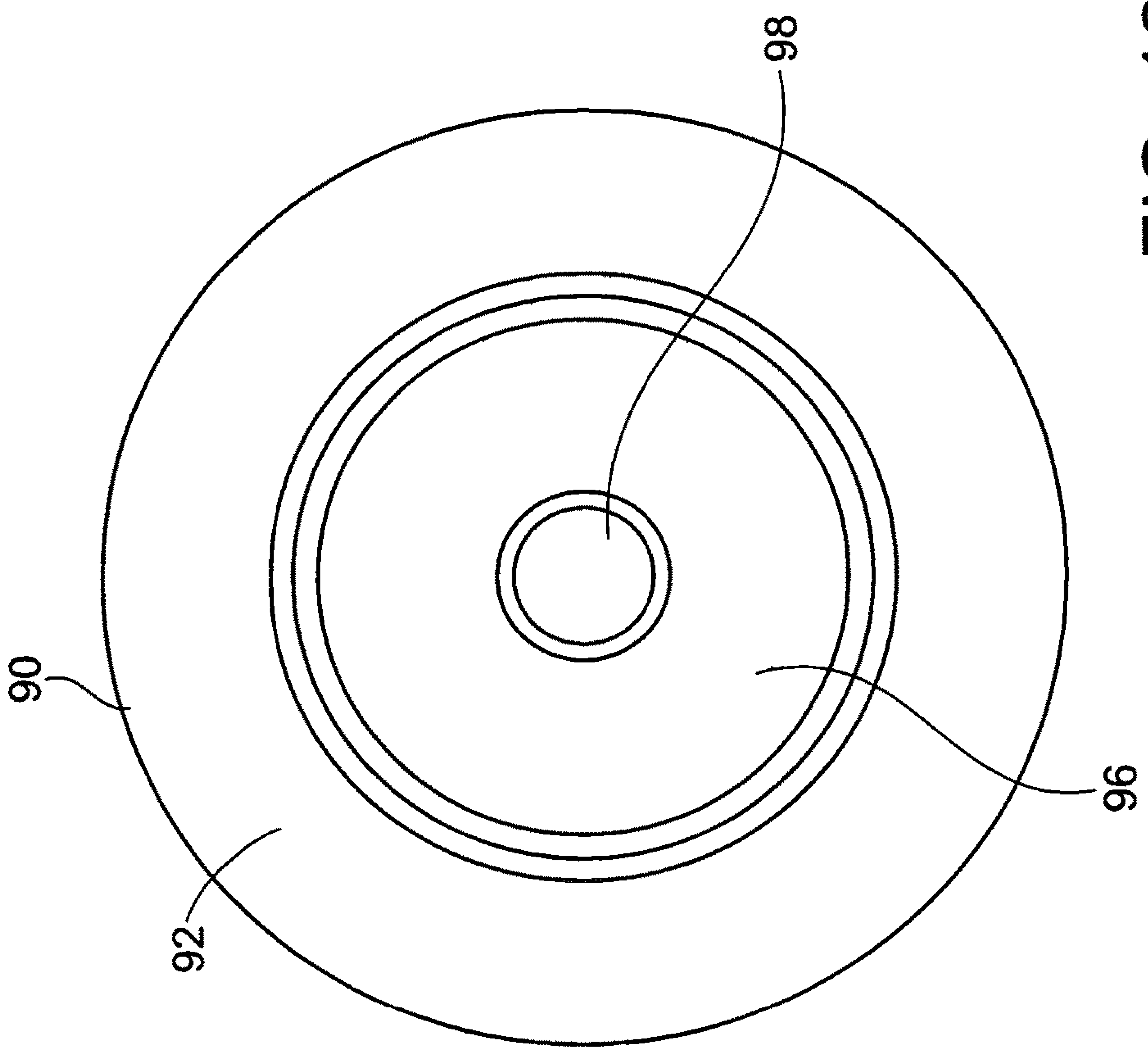


FIG. 12

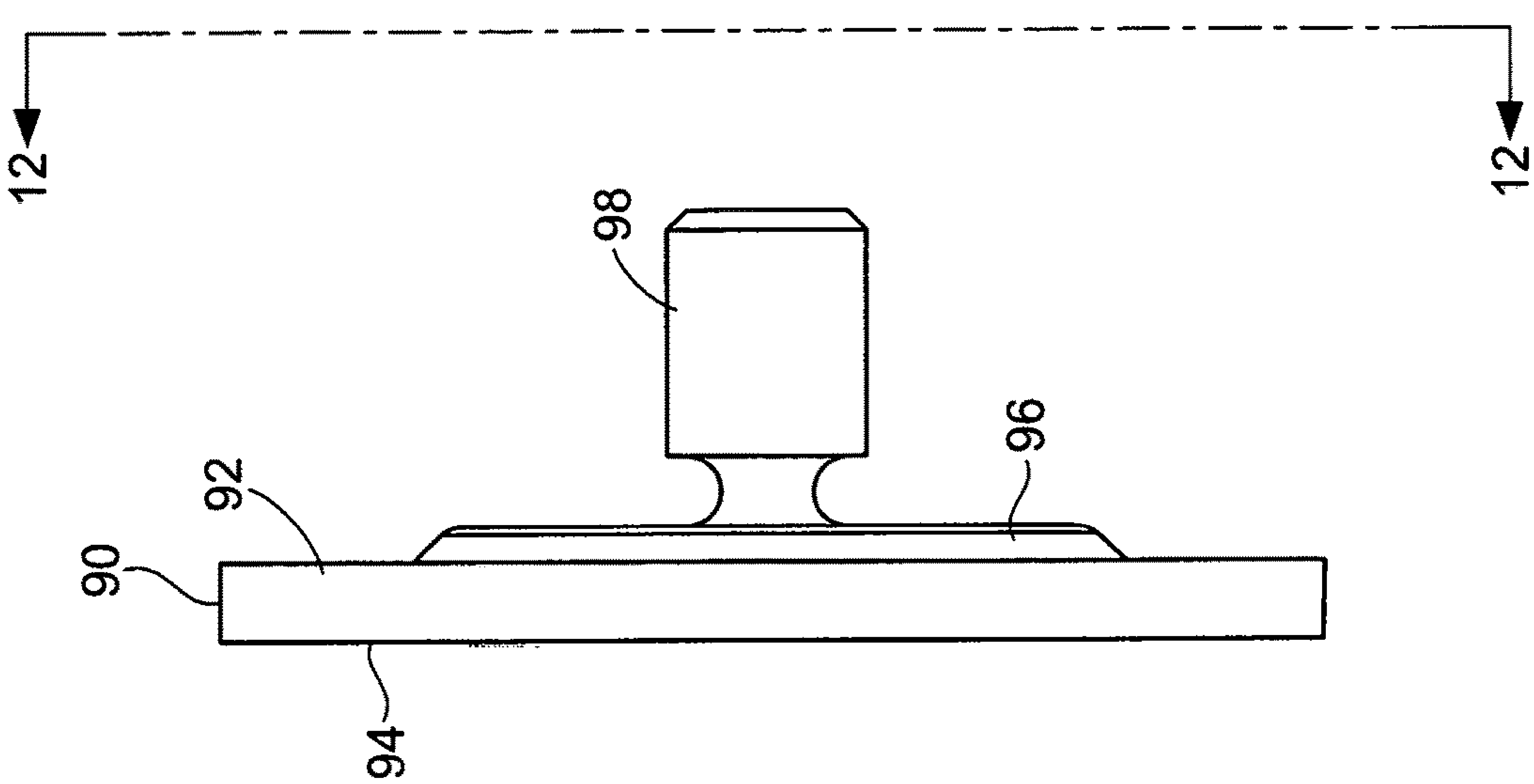


FIG. 11

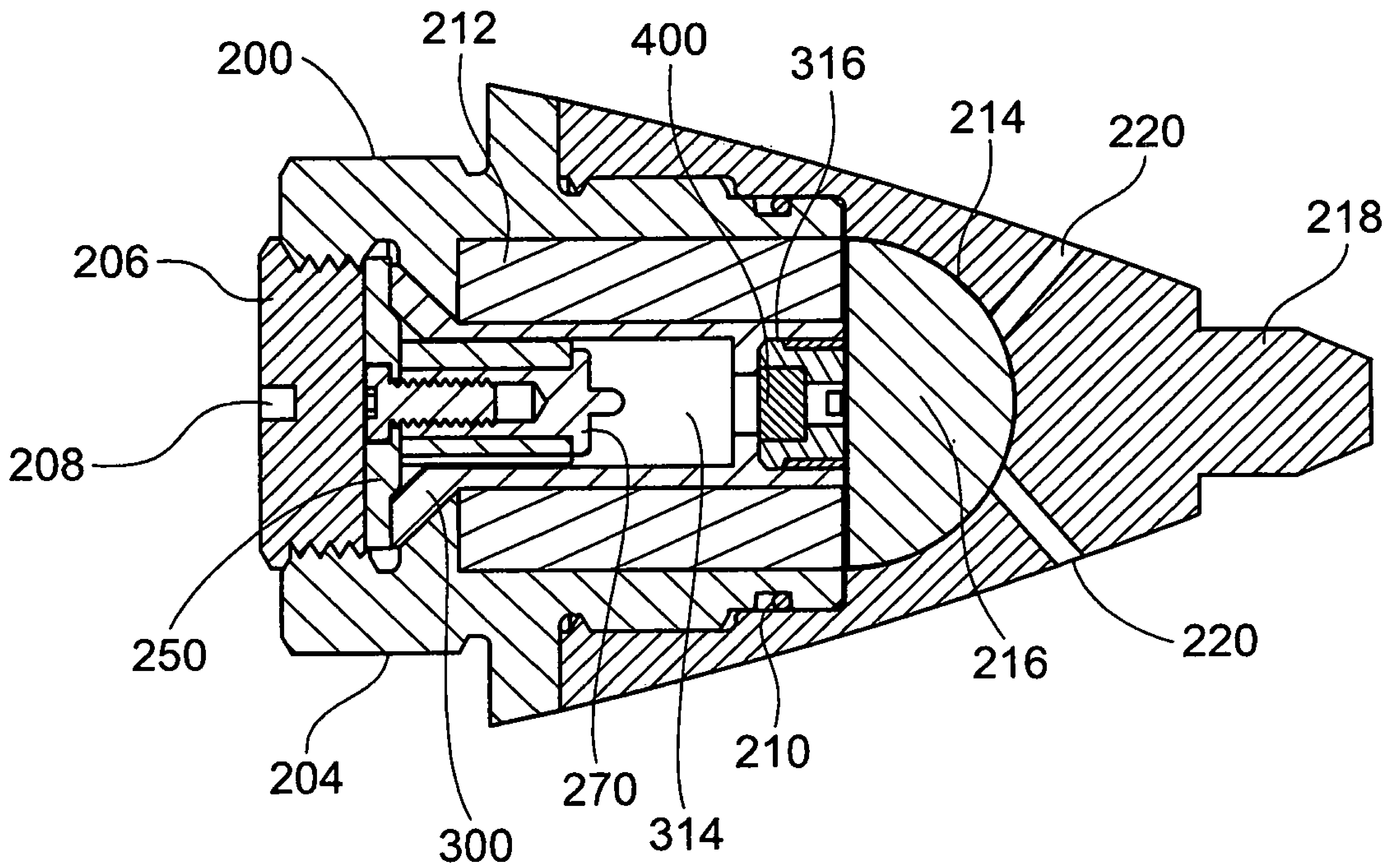

200
212
400
316
214
220
218
206
208
250
204
300
270
314
210
216
220

FIG. 13

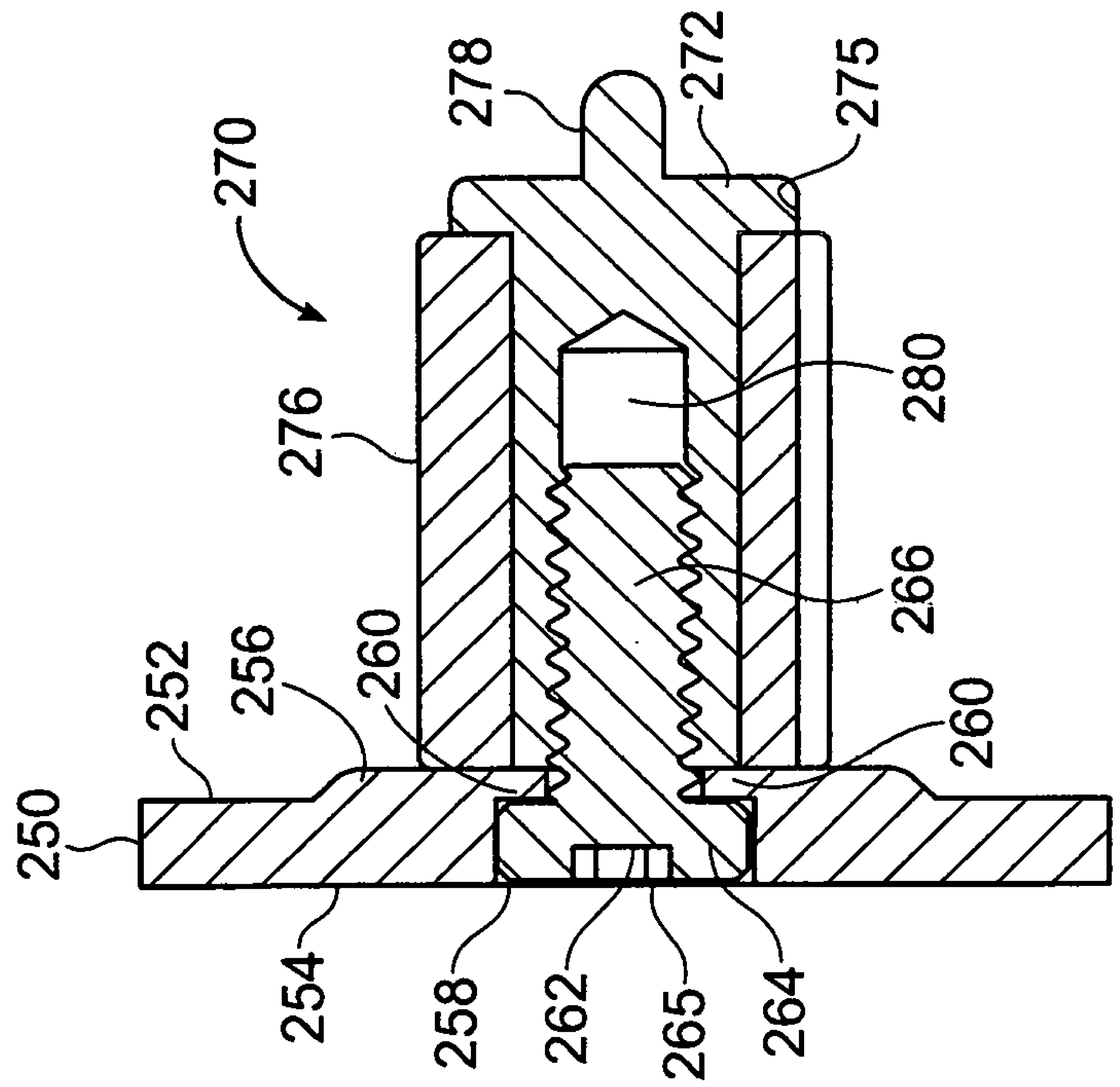

270
278
272
275
276
280
266
252
256
260
260
250
254
258
262
265
264

FIG. 15

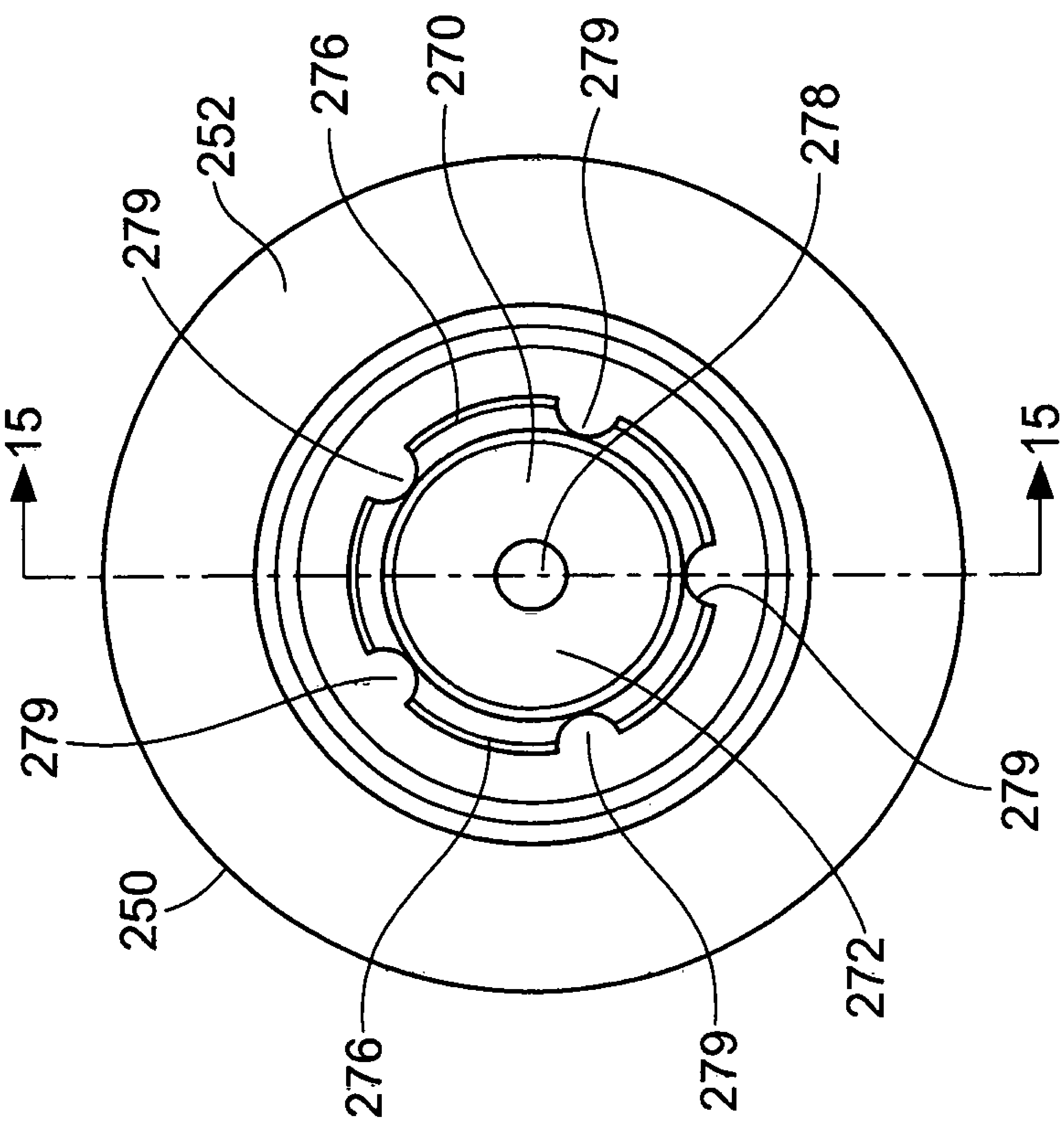

15
15
279
252
276
270
279
278
279
279
250
276
279
272

FIG. 14

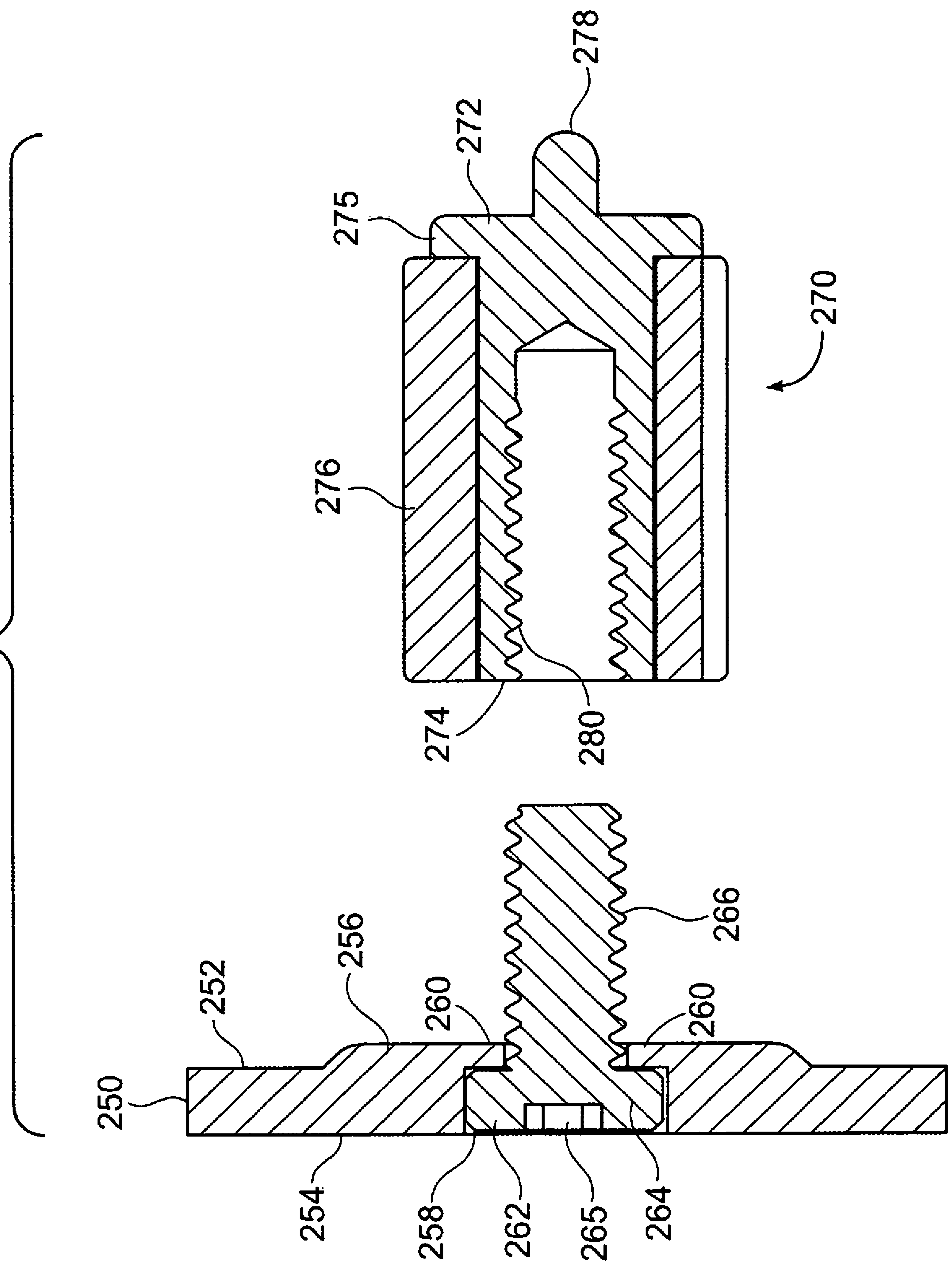

278
272
275
270
276
274
280
266
256
252
260
260
250
254
258
262
265
264

FIG. 16

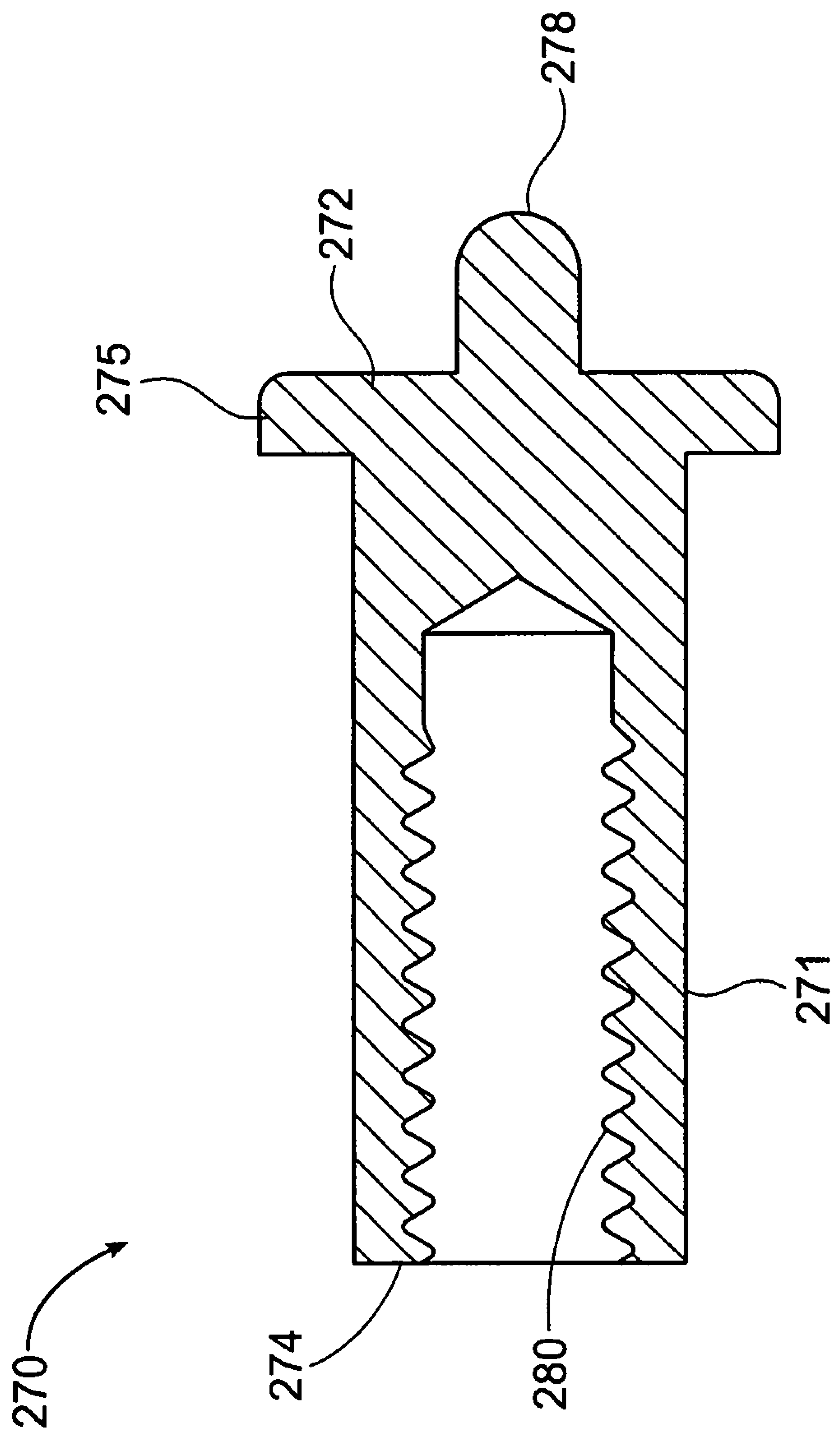


FIG. 17

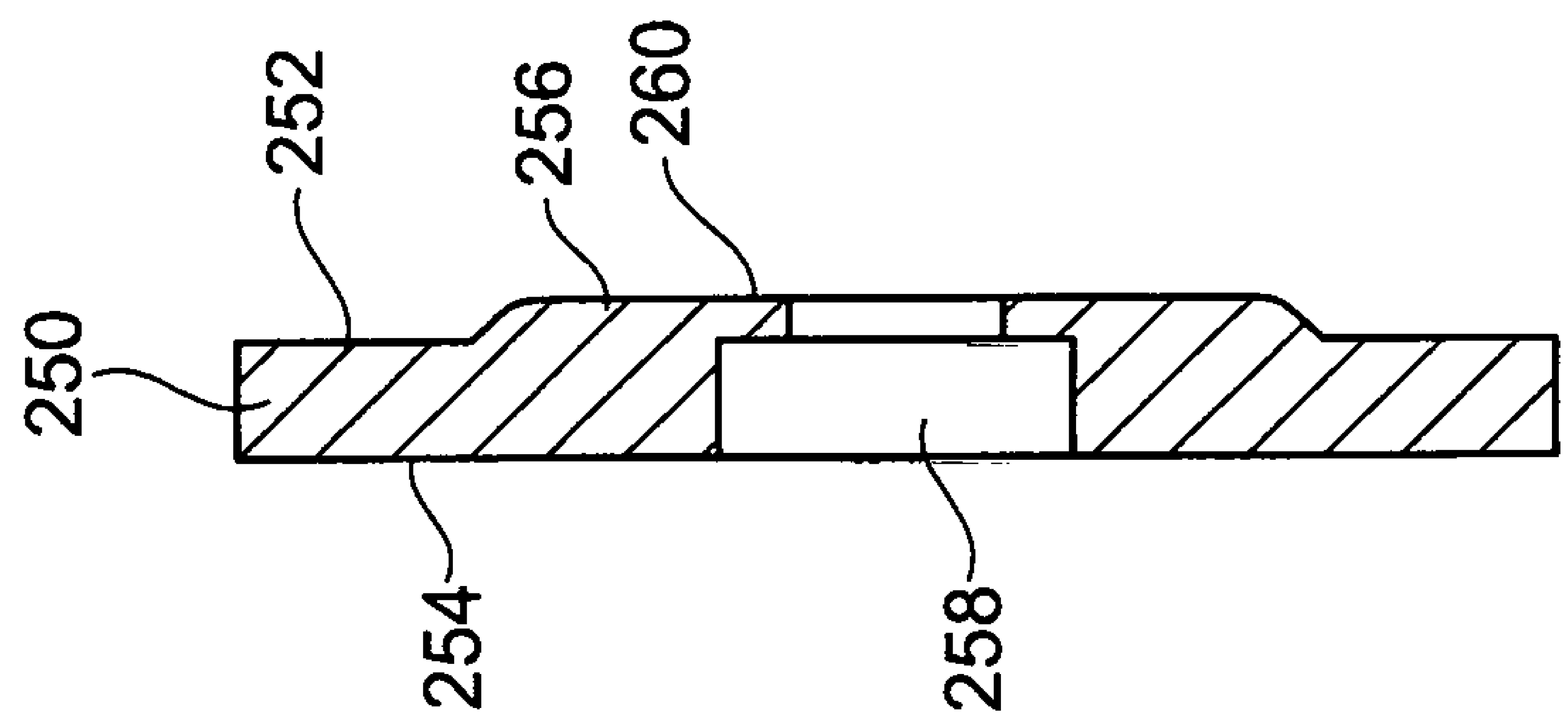


FIG. 19

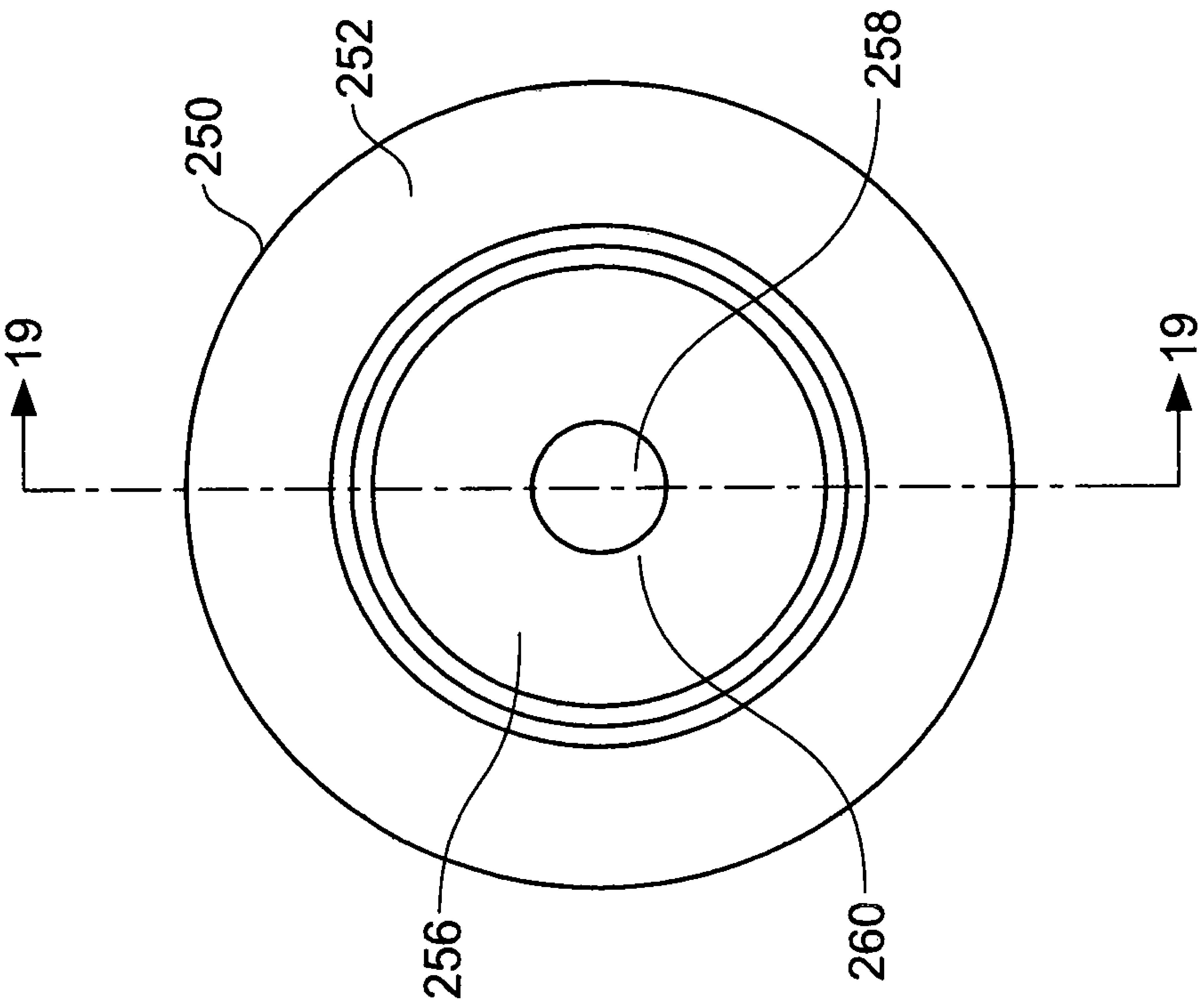


FIG. 18

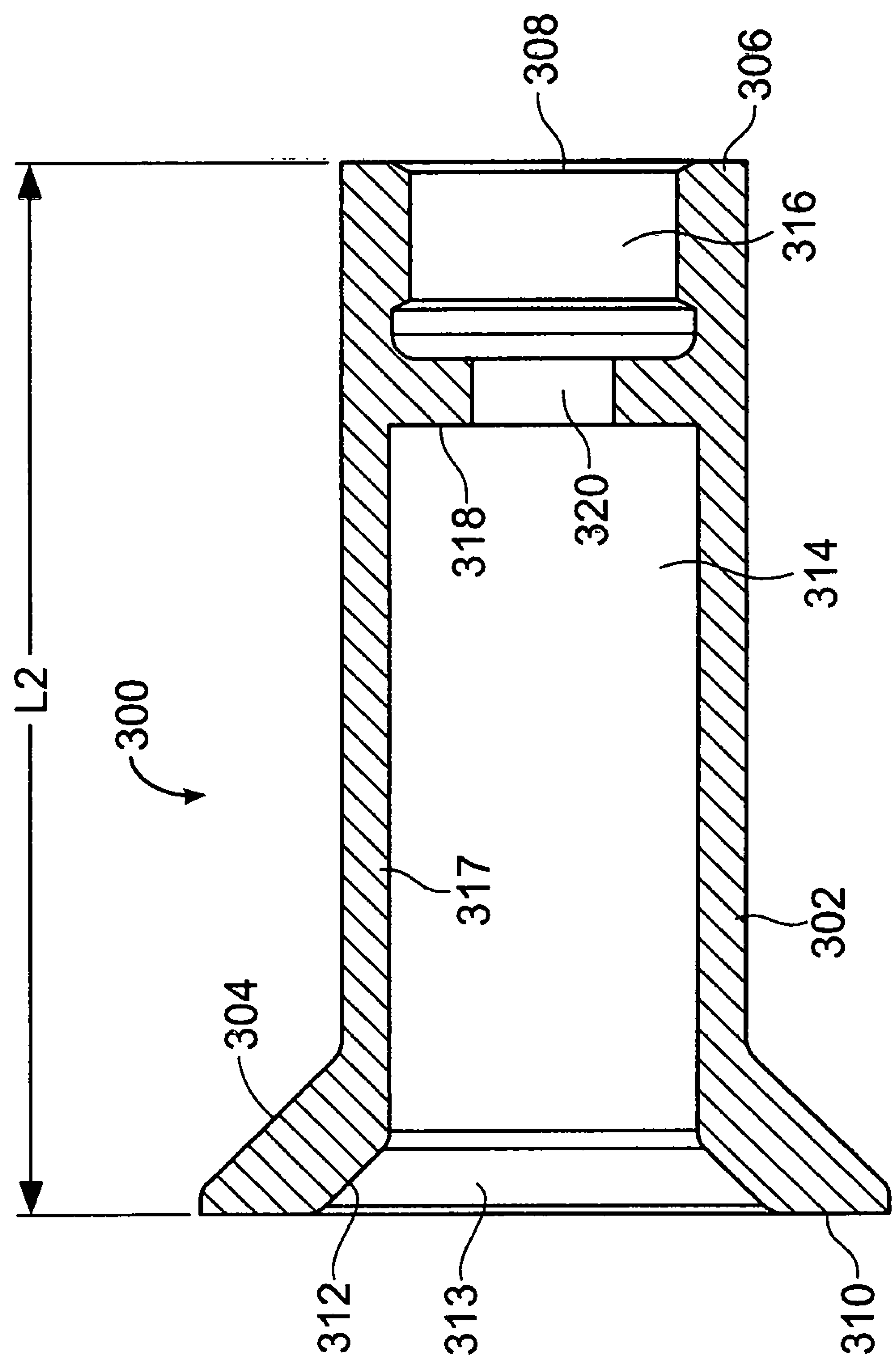


FIG. 20

IGNITION APPARATUS FOR PROJECTILE

STATEMENT OF GOVERNMENT INTEREST

The invention described herein may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

CROSS REFERENCE TO OTHER PATENT APPLICATIONS

None.

TECHNICAL FIELD

The present invention relates to an ignition apparatus for use with projectiles such as artillery projectiles, rockets, missiles or drones.

BACKGROUND

Projectiles with on-board means of chemical propulsion, such as artillery projectiles, rockets, missiles or drones, typically utilize ignition devices that initiate a firing sequence that results in the generation of chemical energy. Such ignition devices utilize inertial components to arm and release a firing pin in the ignition sequence. Typically, ignition devices comprise mechanical ignitions that utilize a firing pin to impact a percussion primer so as to transform the mechanical energy into chemical energy. In many conventional mechanical ignition systems, the required energy for ignition is pre-loaded or stored in a spring system. These springs are compressed or expanded to generate the designed potential energy. The springs are released once predefined conditions occur. A disadvantage of this type of conventional ignition system is a phenomenon known as “creep”. The “creep” phenomenon occurs when a spring maintains a high stress for an extended duration and incurs a permanent deformation that reduces the available energy. Furthermore, in conventional spring loaded ignition systems, the energy is stored and therefor always present but is restrained by a safety mechanism or out-of-alignment orientation. Failure of the safety mechanism or out-of-alignment orientation would cause premature activation of the ignition system.

What is needed is an improved ignition device that does not utilize pre-loaded springs or similar pre-loaded mechanical devices.

SUMMARY

This summary is provided to introduce a selection of concepts in a simplified form that are further described below in the detailed description. This summary is not intended to identify key features or essential features of the claimed subject matter, nor is it intended to be used in isolation as an aid in determining the scope of the claimed subject matter.

Exemplary embodiments of an ignition apparatus are disclosed herein. Each ignition apparatus is configured for use in a projectile that is designed for airborne movement such as an artillery projectile, rocket, missile, drone, etc. In each embodiment disclosed herein, the ignition apparatus initiates an ignition sequence that is the reverse of the ignition sequences implemented by conventional ignition devices that utilize pre-loaded or pre-compressed spring-operated firing pins. Each embodiment of the ignition apparatus disclosed herein utilizes the extreme axial acceleration of the projectile to arm and initiate the ignition sequence. Generally, the projectile is launched or fired from a launching or firing apparatus, respectively. For example, if the projectile is an artillery projectile, then the firing apparatus is an artillery cannon. In such a case, the projectile accelerates through the barrel of artillery cannon after the artillery cannon is fired. This acceleration of the projectile is used to initiate the ignition sequence.

In each of the embodiments of the ignition apparatus disclosed herein, the ignition apparatus includes a housing that is attached or joined to the interior structure of the projectile and a sleeve that is within and attached or joined to the housing. A firing pin is located within the sleeve and is initially held stationary by a fracturable constraint device. The fracturable constraint device abuts an open end of the sleeve. The fracturable constraint device fractures upon being subjected to a predetermined magnitude of force. In one example, the predetermined magnitude of force occurs when the projectile achieves a predetermined magnitude of acceleration as the projectile is accelerating through the barrel of the artillery cannon. In some embodiments, the fracturable constrain device is configured to fracture when it is subjected to a predetermined magnitude of tensile force. In other embodiments, the fracturable constraint device is configured to fracture when it is subjected to a predetermined magnitude of shear force. When the projectile is fired from an artillery cannon, axial acceleration accelerates the projectile through the barrel of the artillery cannon. The firing pin initially resists this axial acceleration. When the axial acceleration of the projectile attains a predetermined magnitude, the inertial mass of the firing pin exerts a tensile or shear force on the fracturable constraint device causing the fracturable constraint device to fracture. Once the fracturable constraint device fractures, the firing pin is released and ceases to accelerate with the projectile. The firing pin now floats within the sleeve and may exhibit axial movement within the sleeve. The projectile and sleeve are now moving with respect to the firing pin. The velocity of the projectile is now greater than the velocity of the firing pin such that a differential velocity exists. This differential velocity increases as the projectile moves through the barrel. The percussion primer is positioned within the sleeve and located at the lengthwise end of the sleeve that is opposite the end of the sleeve where the fracturable constraint device is located. Since the sleeve is attached to the interior structure of the projectile and the percussion primer is secured within the sleeve, the percussion primer accelerates with the projectile and is moving toward the floating firing pin as the projectile accelerates out of the barrel. The sleeve has a predetermined length that is sufficient to allow the percussion primer to accelerate into the firing pin with an impact that is sufficient to activate the percussion primer. Once activated, the percussion primer produces hot particles and gases that initiate combustion of energetic material stored within an adjacent combustion chamber. One example of such energetic material is Boron Potassium Nitrate ($BKNO_3$). The combustion of the energetic material in the combustion chamber causes combustion of a cylindrical solid propellant casting that extends about the sleeve and which is adjacent to the combustion chamber. Once combustion starts, the cylindrical solid propellant casting continues to combust until fully consumed. The combustion of the cylindrical solid propellant casting produces hot combustion products that flow through a plurality of gas ports and into a ramjet combustor of the projectile. The hot

combustion products activate an onboard ramjet. The ignition apparatus may be configured in accordance with a particular geometry of the projectile or with the specific mechanical energy required to activate a percussion primer.

In some exemplary embodiments, the ignition apparatus includes a housing having an interior and a rear central opening in communication with the interior. A sleeve is positioned within the interior of the housing and has a predetermined length, an interior space, a front end having a front opening and a rear end having a rear opening. The front opening and rear opening of the sleeve are in in communication with the interior space and the rear opening of the sleeve is aligned with the rear central opening of the housing. The ignition apparatus further includes a fracturable constraint device that is positioned within the interior of the housing and is adjacent to the rear central opening. The fracturable constraint device has a front side that is in abutting relation with the rear end of the sleeve and a rear side that faces the rear central opening. The fracturable constraint device is configured to fracture when subjected to a predefined magnitude of force caused by axial acceleration of the projectile. The ignition apparatus further includes a cap that is attached to the housing and is positioned within the rear central opening. The cap abuts the rear side of the fracturable constraint device such that the fracturable constraint device is maintained in abutting relation with the rear end of the sleeve. A firing pin is positioned within the interior space of the sleeve and is configured to have high-density so as to provide high inertial mass. The firing pin is secured to the fracturable constraint device. A percussion primer positioned within the interior space of the sleeve and is spaced apart from the firing pin. The fracturable constraint device fractures upon being subjected to the predefined magnitude of force thereby setting free the firing pin such that the firing pin does not accelerate with the projectile and is free to move within the interior space of the sleeve. Whereby, sustained axial acceleration of the projectile, the predetermined length of the sleeve and the high density portion of the firing pin cooperate to enable the firing pin to impact with the percussion primer with a force that is sufficient to activate the percussion primer.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a side elevational view, partially in cross-section, of the front portion of a projectile having therein an exemplary embodiment of the ignition apparatus, the view showing a portion of the projectile cut away in order to facilitate viewing of the ignition apparatus which is located within the interior of the projectile;

FIG. **2** is a rear end view of the ignition apparatus, the view showing a housing and cap member attached to the housing;

FIG. **3** is a side view, in elevational and partially in cross-section, of a housing, combustion chamber and nozzle cap shown in FIG. **1**;

FIG. **4**A is a cross-sectional view of the ignition apparatus without the cap member, combustion chamber and nozzle cap;

FIG. **4**B is an front view of the cap member;

FIG. **4**C is a cross-sectional view taken along line **4**C-**4**C of FIG. **4**B;

FIG. **5** is a side elevational view of a firing pin shown in FIG. **1**;

FIG. **6** is a rear end view of the firing pin taken along line **6-6** of FIG. **5**;

FIG. **7** is a view of the firing pin secured to a fracturable constraint device as seen from the front of the firing pin;

FIG. **8** is a cross-sectional view taken along line **8-8** of FIG. **7**;

FIG. **9** is a rear end view of a firing pin sleeve shown in FIG. **1**;

FIG. **10** is a cross-sectional view taken along line **10-10** of FIG. **9**;

FIG. **11** is a side-elevational view of the fracturable constraint device shown in FIGS. **1**, **7** and **8**;

FIG. **12** is a view taken along line **12-12** of FIG. **11**;

FIG. **13** is a cross-sectional view of an ignition apparatus in accordance with another exemplary embodiment;

FIG. **14** is a front elevational view showing a firing pin, a high-density ring attached to the fire pin and a fracturable constraint device, all of which being shown in FIG. **13**, the firing pin being attached to the fracturable constraint device;

FIG. **15** is a cross-sectional view taken along line **15-15** of FIG. **14**;

FIG. **16** is an exploded view showing the firing pin, high-density ring and fracturable constraint device of FIG. **14**;

FIG. **17** is a cross-sectional view of the firing pin shown in FIGS. **14**, **15** and **16**, the view showing the firing pin without the high-density ring in order to facilitate viewing of the firing pin;

FIG. **18** is a front view of a shear disc shown in FIGS. **13-16**;

FIG. **19** is a cross-sectional view taken along line **19-19** of FIG. **18**; and

FIG. **20** is a cross-sectional view of the sleeve shown in FIG. **13**.

DETAILED DESCRIPTION

As used herein, the terms “comprises”, “comprising”, “includes”, “including”, “has”, “having” or any other variation thereof, are intended to cover a non-exclusive inclusion. For example, a process, method, article or apparatus that comprises a list of elements is not necessarily limited to only those elements, but may include other elements not expressly listed or inherent to such process, method, article or apparatus.

It is to be understood that throughout this description, terms such as “vertical”, “horizontal”, “top”, “bottom”, “upper”, “lower”, “middle”, “above”, “below” and the like are used for convenience in identifying relative locations of various components and surfaces relative to one another in reference to the drawings and are not intended to be limiting in any way.

Reference in the specification to “an exemplary embodiment”, “one embodiment” or “an embodiment” means that a particular feature, structure or characteristic described in connection with the embodiment is included in at least one embodiment of the invention. The appearances of the phrases “an exemplary embodiment”, “one embodiment” or “embodiment” in various places in the specification are not necessarily all referring to the same embodiment.

Approximating language, as used herein throughout the specification and claims, may be applied to modify any quantitative representation that could permissibly vary without resulting in a change in the basic function to which it is related. Accordingly, a value modified by a term such as “about” or “approximately” is not limited to the precise value specified.

Referring to FIG. **1**, there is shown a side elevational view, partially in cross-section, of a front portion of projectile **20** having interior region **22** and an interior structure and wall (not shown). For purposes of describing the embodiments herein, the ensuing description is in terms of projectile **20** being configured as an artillery projectile fired from an artillery cannon having a barrel. The view in FIG. **1** shows a portion of projectile **20** cut away in order to facilitate viewing of interior region **22** of projectile **20**. Positioned within interior region **22** is ignition apparatus **24** in accordance with an exemplary embodiment of the present invention. Ignition apparatus **24** is positioned adjacent to telemetry module **26**, which includes electronic components that are pertinent to the operation and flight of projectile **20**. Telemetry module **26** is attached or mounted to the interior structure or wall of projectile **20**. Telemetry module **26** is well known in the art and is therefore not described herein in detail.

Referring to FIGS. **1**, **2**, **3**, **4**A, **4**B and **4**C, ignition apparatus **24** includes housing **30** that is attached, joined or secured to the interior structure (not shown) of projectile **20**. Housing **30** includes a circumferentially extending grove **31** for receiving seal **32**. Seal **32** provides a seal between housing **30** and the interior structure (not shown) of projectile **20**. In an exemplary embodiment, housing **30** has a substantially cylindrical shape. Housing **30** has rear end **33**, front end **34** and circumferentially extending flange portion **35**. Rear end **33** extends about central opening **36** (see FIG. **4**A). Central opening **36** is sized to receive cap member **38**. Cap member **38** is also shown in FIGS. **4**B and **4**C. In an exemplary embodiment, cap member **38** includes circumferentially extending threads **40** that are configured to engage corresponding threads **42** that are on housing **30** and which extend about central opening **36**. Cap member **38** includes slot **44** therein that is configured to receive a tool (not shown) that is used to screw cap member **38** into central opening **36**. In other embodiments, cap member **38** is frictionally fitted within central opening **36**.

Referring to FIGS. **1**, **4**A, **9** and **10**, ignition apparatus **24** further includes sleeve **46** that is located within housing **30**. In an exemplary embodiment, sleeve **46** is fabricated from metal. Suitable metals include, but are not limited to, Aluminum, steel, iron, copper and brass. In other exemplary embodiments, sleeve **46** is fabricated non-metal materials. Examples of such non-metal materials include, but are not limited to, plastic, resin, PVC, and composites. Sleeve **46** is adjacent to combustion chamber **120**. Combustion chamber **120** is located within nozzle cap **121**. Combustion chamber **120** is discussed in detail in the ensuing description. In an exemplary embodiment, sleeve **46** is press-fitted into a bore or internal space or region of housing **30**. Sleeve **46** has a predetermined length L**1** (see FIG. **10**). Sleeve **46** has an interior space that includes first interior space **48** that is sized for holding firing pin **100**, which is discussed in detail in the ensuing description. Sleeve **46** includes substantially cylindrical section **50**, angulated portion **52** and front end **54**. Front end **54** has opening **55**. The interior space of sleeve **46** further comprises second interior space **56** that is sized for holding percussion primer **80** which is discussed in the ensuing description. Sleeve **46** further includes rear end **57** which has beveled portion **57**A. Sleeve **46** includes interior wall **58**. Interior wall **58** includes internal structure **59** that is located between first interior space **48** and second interior space **56**. Internal structure **59** is configured to provide angulated portion **60**. Angulated portion **60** defines a substantially conical shape that corresponds to the conical shape of forward portion **102** of firing pin **100**. These aspects of ignition apparatus **24** are discussed in detail in the ensuing description. As shown in FIG. **10**, internal structure **59** includes central opening **62** that allows first interior space **48** to be in communication with second interior space **56**. Internal structure **59** is configured so that the diameter of central opening **62** is substantially smaller than the diameter of opening **63** in rear end **57** of sleeve **46**. Central opening **62** is sized to allow nose portion **104** of firing pin **100** to protrude through central opening **62** and extend into second interior space **56** so as to physically contact percussion primer **80**. FIG. **10** does not show percussion primer **80** in order to facilitate viewing of second interior space **56**. When percussion primer **80** is positioned within second interior space **56**, percussion primer **80** abuts internal structure **59**. Opening **63** in rear end **57** is in communication with first interior space **48** and is sized for receiving firing pin **100**. As shown in FIGS. **1** and **4**A, ignition apparatus **24** further includes cylindrical solid propellant casting **64** that is located within housing **30** and positioned between the inner wall of housing **30** and sleeve **46**. Since solid propellant casting **64** is cylindrically shaped, it extends about sleeve **46**. The purpose of solid propellant casting **64** is discussed in detail in the ensuing description.

Referring to FIGS. **1**, **11** and **12**, ignition apparatus **24** further includes fracturable constraint device **90**. Fracturable constraint device **90** fractures upon being subjected to a predetermined magnitude of force. The predetermined magnitude of force occurs when projectile **20** achieves a predetermined magnitude of acceleration. Fracturable constraint device **90** is substantially circular in shape and includes front side **92** and rear side **94**. In an exemplary embodiment, fracturable constraint device **90** is fabricated from a thermoplastic polymer. An example of such a thermoplastic polymer is PEEK (Polyether Ether Ketone). In other embodiments, fracturable constraint device **90** is fabricated from an Acrylic Resin. As shown in FIG. **1**, cap member **38** is screwed into central opening **36** in housing **30** until cap member **38** is in abutting relation with rear side **94** of fracturable constraint device **90**. In this configuration, cap member **38** keeps front side **92** of fracturable constraint device **90** in physical contact with rear end **57** of sleeve **46**. Fracturable constraint device **90** further includes base portion **96** and protruding portion **98**. Protruding portion **98** outwardly extends from base portion **96**. Protruding portion **98** is integral with base portion **96**. In an exemplary embodiment, protruding portion **98** has a knob-like shape. Protruding portion **98** is sized to fit within bore **105** in firing pin **100**. Bore **105** has inner wall **106** (see FIGS. **1** and **6**). An epoxy is used to attach protruding portion **98** to inner wall **106**. In other embodiments, protruding portion **98** is sized to frictionally fit within bore **105** in firing pin **100**. Fracturable constraint device **90** is configured to have a relatively low strain rate so that it will fracture during axial acceleration of projectile **20**. During such axial acceleration, projectile **20** is moving through the barrel from right to left when viewing FIG. **1**. Such axial acceleration produces tensile force on fracturable constraint device **90**. When the tensile force reaches a predetermined magnitude, protruding portion **98** breaks off the base portion **96** thereby setting free firing pin **100**. Once free, firing pin **100** is free to move with respect to sleeve **46**. Thus, firing pin **100** may move from left to right when viewing FIG. **1**.

Referring to FIGS. **1**, **4**A, **5** and **6**, firing pin **100** comprises forward section **102** and body section **103**. In an exemplary embodiment, forward section **102** is joined or attached to body section **103**. Forward section **102** has a substantially conical shape and includes nose portion **104**. The conical shape of forward portion **102** corresponds to the conical shape provided by angulated portion **60** as discussed in the foregoing description. In an exemplary embodiment, body section **103** has a substantially cylindrical shape. Body section **103** includes bore **105** which was discussed in the foregoing description. Bore **105** has inner wall **106** for receiving protruding portion **98** of fracturable constraint device **90** as discussed in the foregoing description. Body section **103** includes rear end **107** which abuts base portion **96** of fracturable constraint device **98**. Body section **103** includes at least one longitudinally extending channel **108** formed therein. In an exemplary embodiment, there is a plurality of channels **108** that are equidistantly spaced. Channels **108** prevent compressed air from interfering with the movement of firing pin **100** once fracturable constraint device **90** fractures and firing pin **100** is set free. First interior space **48** of sleeve **46** is a closed volume that contains trapped air. Without channels **108**, this trapped air would compress when firing pin **100** attempts to move toward percussion primer **80** or when percussion primer **80** approaches firing pin **100** due to the movement projectile **20**. Such air compression would cause deceleration of firing pin **100**. However, channels **108** allow the air within the closed volume to pass around firing pin **100** thereby eliminating any compression of air. In an exemplary embodiment, body section **103** is fabricated from a high-density material in order provide high inertial mass so as to maximize the impact of firing pin **100** on percussion primer **80**. In an exemplary embodiment, the high-density material is Tungsten. However, other suitable high-density materials also may be used.

After projectile **20** is launched or fired, projectile **20** accelerates through the barrel. Fracturable constraint device **90** remains intact until projectile **20** achieves a predetermined rate of axial acceleration. The predetermined rate of acceleration translates into a predetermined magnitude of force being applied to fracturable constraint device **90**. In response to the applied predetermined magnitude of force, protruding portion **98** breaks off of fracturable constraint device **90** thereby releasing firing pin **100**. When firing pin **100** is released, it ceases to accelerate with projectile **20**. Firing pin **100** now floats within sleeve **46** and may exhibit axial movement toward percussion primer **80**. Projectile **20** is now moving with respect to firing pin **100**. The velocity of projectile **20** is now greater than the velocity of firing pin **100** such that a differential velocity exists. This differential velocity increases as projectile **20** moves through the barrel. As shown in FIG. **1**, percussion primer **80** is located at the lengthwise end of sleeve **46** that is opposite the fracturable constraint device **90**. Percussion primer **80** is positioned within second interior space **56** of sleeve **46**. Therefore, sleeve **46** and percussion primer **80** accelerate with projectile **20** and move toward the floating firing pin **100** as projectile **20** is accelerating out of the barrel. The predetermined length L**1** of sleeve **46** allows percussion primer **80** to accelerate toward firing pin **100** such that nose portion **104** of firing pin **100** passes through central opening **62** (see FIG. **10**) and impacts with percussion primer **80** with a force that is sufficient to activate percussion primer **80**. Once activated, percussion primer **80** produces hot particles and gases that initiate combustion of energetic material **122** that is stored within the adjacent combustion chamber **120**. One example of such energetic material is Boron Potassium Nitrate ($BKNO_3$). Cylindrical solid propellant casting **64** extends about sleeve **46** and is exposed to the interior of combustion chamber **120**. The combustion of the energetic material **122** in combustion chamber **120** causes combustion of cylindrical solid propellant casting **64**. Once combustion starts, cylindrical solid propellant casting **64** continues to combust until fully consumed. The combustion of cylindrical solid propellant casting **64** produces hot combustion products that flow through a plurality of gas ports **130** in nozzle cap **121** and into ramjet combustor **132** of projectile **20**. These hot combustion products activate the ramjet (not shown).

Referring to FIG. **13**, there is shown ignition apparatus **200** in accordance with another exemplary embodiment. Ignition apparatus **200** is positioned within a projectile (not shown) that is substantially the same in configuration as projectile **20** which was discussed in the foregoing description. Ignition apparatus **200** comprises housing **204** which has the same structure and function as the structure and function, respectively, as housing **30** which was discussed in the foregoing description. Ignition apparatus **200** further includes cap member **206**, which has the same structure and function as the structure and function, respectively, as cap member **38** which was discussed in the foregoing description. Cap member **206** includes slot **208** which serves the same purpose as slot **44** of cap member **38**. Housing **200** includes a central opening in rear end portion **208** which has the same shape and configuration as central opening **36** of housing **30** which was discussed in the foregoing description. Cap member **206** is screwed into the central opening in the rear end portion **208** in the same manner as cap member **38** is screwed into central opening **36** of housing **30**. Ignition apparatus **200** includes seal **210**, which has the same configuration and function as seal **32** which is shown in FIG. **1**. Cylindrical solid propellant casing **212** has the same structure and function as cylindrical solid propellant casing **64** which was discussed in the foregoing description. Combustion chamber **214** contains energetic material **216**. Combustion chamber **214** and energetic material **216** perform the same function as combustion chamber **210** and energetic material **122**, respectively, which were discussed in the foregoing description. Combustion chamber **214** is within nozzle cap **218**. Nozzle cap **218** performs the same function as nozzle cap **121** which was discussed in the foregoing description. Nozzle cap **218** includes exhaust ports **220** which perform the same function as exhaust ports **130** discussed in the ensuing description.

Referring to FIGS. **13-16**, ignition apparatus **200** further includes fracturable constraint device **250**. Similar to fracturable constraint device **90** that was discussed in the foregoing description, fracturable constraint device **250** fractures upon being subjected to a predetermined magnitude of force. The predetermined magnitude of force occurs when the projectile achieves a predetermined magnitude of acceleration. In this particular embodiment, fracturable constraint device **250** is configured as a "shear disc." Accordingly, fracturable constraint device **250** is substantially circular in shape and includes front side **252** and rear side **254**. In an exemplary embodiment, fracturable constraint device **250** is fabricated from thermoplastic polymer. An example of such a thermoplastic polymer is PEEK (Polyether Ether Ketone). In another exemplary embodiment, fracturable constraint device **250** is fabricated from Acrylic Resin. As shown in FIG. **13**, cap member **206** is screwed into the central opening in the rear end portion of housing **204** until cap member **206** abuts rear side **254** of fracturable constrain device **250**. Fracturable constraint device **250** further includes central base portion **256**. As shown in FIGS. **18** and **19**, central base portion **256** has central opening **258** and overhanging portion **260** that extends about and hangs over central opening **258**. As shown in FIG. **16**, bolt **262** is secured to fracturable constraint device **250**. Specifically, bolt **262** includes head **264** that is lodged within central opening **258** and abuts portion **260**. Head **264** has slot **265** that is sized to receive a tool such as a screw driver or other tool that can rotate bolt **262**. Bolt **262** includes longitudinally extending threaded shank or stem **266** that is joined to or integral with head portion **264**. In an exemplary embodiment, shank **266** is integral with head portion **264**. As shown in FIG. **16**, shank **266** has threads **268** thereon. The purpose of threads **268** is explained in detail in the ensuing description. In an exemplary embodiment, bolt **262** is fabricated from metal. Suitable metals include steel or stainless steel, iron, copper, brass, etc.

Referring to FIGS. **13-17**, ignition apparatus **200** further comprises firing pin **270**. Firing pin **270** is located within sleeve **300** which is discussed in detail in the ensuing description. Firing pin **270** has a generally cylindrical shaped section **271** and includes front end **272** and rear end **274**. In an exemplary embodiment, generally cylindrical shaped section **271**, front end **272** and rear end **274** are fabricated from metal. Suitable metals include, but are not limited to, Aluminum, steel, iron, copper and brass. Rear end **274** abuts front side **252** of fracturable constraint device **250**. Firing pin **270** further includes circumferentially extending flanged portion **275**. Firing pin **270** includes circumferentially extending high-density ring **276** that is attached, joined or mounted to cylindrical shaped section **271** and abuts flanged portion **275**. High-density ring **276** provides inertial mass that ensures firing pin **270** will impact percussion primer **400** with a force sufficient to ignite percussion primer **400**. Thus, high-density ring **276** maximizes the impact of firing pin **270** on percussion primer **400**. In an exemplary embodiment, high-density ring **276** is fabricated from Tungsten. However, other suitable high-density materials also may be used to fabricate high-density ring **276**. Firing pin **270** has protruding portion **278** that extends outwardly from front end **272**. As will be explained in the ensuing description, protruding portion **278** is configured to strike percussion primer **400** (see FIG. **13**). Firing pin **270** includes a plurality of longitudinally extending channels **279** (see FIG. **14**) that provide the same function as channels **108** which were discussed in the foregoing description. Firing pin **270** includes threaded bore **280**. As shown in FIG. **15**, threaded shank **266** is screwed into threaded bore **280**. Fracturable constraint device **250** is configured to have a relatively low strain rate so that it will fracture during axial acceleration of the projectile. During such axial acceleration, the projectile is moving through the barrel and the axial acceleration produces shearing forces on fracturable constraint device **250** and bolt **262**. When the shearing force reaches a predetermined magnitude, head portion **264** of bolt **262** rips through the material of fracturable constraint device **250** and breaks free of fracturable constraint device **250**. As a result, firing pin **270** is set free. Firing pin **270** is now free to move with respect to sleeve **300**. Thus, firing pin **270** may move from left to right, when viewing FIG. **13**.

Referring to FIGS. **13** and **20**, ignition apparatus **200** further includes sleeve **300** that is located within housing **204**. In an exemplary embodiment, sleeve **300** is fabricated from metal. Suitable metals include, but are not limited to, Aluminum, steel, iron, copper and brass. In other embodiments, sleeve **300** is fabricated non-metal materials. Examples of such non-metal materials include, but are not limited to, plastic, resin, PVC, and composites. Sleeve **300** is adjacent to combustion chamber **214**. In an exemplary embodiment, sleeve **300** is press-fitted into a bore or interior region of housing **204**. Sleeve **300** has a predetermined length L2 (see FIG. **20**) and includes substantially cylindrical section **302**, angulated portion **304** and front end **306**. Front end **306** has opening **308**. Angulated portion **304** defines rear end **310**. Rear end **310** has beveled portion **312** and central opening **313**. As shown in FIG. **13**, rear end **310** abuts front side **252** of fracturable constraint device **250**. Sleeve **300** has an interior space that comprises first interior space **314** which is in communication with central opening **313** and sized for holding firing pin **270**. Firing pin **270** is not shown in FIG. **20** so as to facilitate viewing of the interior region of sleeve **300**. The interior space of sleeve **300** further comprises second interior space **316** which is sized for holding percussion primer **400** (see FIG. **13**). Percussion primer **400** has the same function and configuration as percussion primer **80** which was discussed in the foregoing description. Percussion primer **400** is not shown in FIG. **20** so as to facilitate viewing of second interior space **316** of sleeve **300**. Sleeve **300** includes interior surface **317** and internal structure **318** that is between first interior space **314** and second interior space **316**. In an exemplary embodiment, internal structure **318** is integral with sleeve **300** and is not a separate component. In other embodiments, internal structure **318** is attached or joined to the interior surface **317** by any suitable technique, e.g. welding, brazing, etc. As shown in FIG. **20**, internal structure **318** includes central opening **320** that allows first interior space **314** to be in communication with second interior space **316**. Central opening **320** is sized to allow protruding portion **278** of firing pin **270** to protrude through central opening **320** and extend into second interior space **316** in order to strike percussion primer **400**. When percussion primer **400** is positioned within second interior space **316**, percussion primer **400** abuts internal structure **318**. As shown in FIG. **13**, cylindrical solid propellant casting **212** is extends about sleeve **300**.

After the projectile is launched or fired, the projectile accelerates through the barrel. Fracturable constraint device **250** remains intact until the projectile achieves a predetermined rate of axial acceleration. The predetermined rate of acceleration produces a predetermined magnitude of shearing force that is applied to or exerted upon fracturable constraint device **250** and bolt **262**. In response to this shearing force, head **264** of bolt **262** breaks off of fracturable constraint device **250** thereby releasing firing pin **270**. When firing pin **270** is released, it ceases to accelerate with the projectile. Firing pin **270** now floats within sleeve **300** and may exhibit movement toward percussion primer **400**. The projectile is now moving with respect to firing pin **270**. The velocity of the projectile is now greater than the velocity of firing pin **270** such that a differential velocity exists. This differential velocity increases as the projectile moves through the barrel. As shown in FIG. **13**, percussion primer **400** is located at the lengthwise end of sleeve **300** that is opposite fracturable constraint device **250**. Percussion primer **400** is positioned within second interior space **316** of sleeve **300**. Therefore, sleeve **300** and percussion primer **400** accelerate with the projectile and move toward floating firing pin **270** as the projectile is accelerating out of the barrel. The predetermined length L2 of sleeve **300** allows percussion primer **400** to accelerate toward firing pin **270** so that protruding member **278** of firing pin **270** passes through central opening **320** and strikes percussion primer **400** with sufficient impact to activate percussion primer **400**. Once activated, percussion primer **400** produces hot particles and gases that initiate combustion of energetic material **216** that is stored within the adjacent combustion chamber **214**. One example of such energetic material is Boron Potassium Nitrate ($BKNO_3$). Cylindrical solid propellant casting **212** extends about sleeve **300** and is exposed to the interior of combustion chamber **214**. The combustion of energetic material **216** in combustion chamber **214** causes combustion of cylindrical solid propellant casting **212**. Once combustion starts, cylindrical solid propellant casting **212** continues to combust until fully consumed. The combustion of cylindrical solid propellant casting **212** produces hot combustion products that flow through a plurality of exhaust ports **220** in nozzle cap **218** and into the ramjet combustor (not shown in FIG. **13**). Such hot combustion products activate the ramjet (not shown).

In contrast to the conventional ignition devices, the exemplary embodiments of the ignition apparatus disclosed herein do not use pre-loaded springs or other pre-loaded devices thereby eliminating the problems and limitations associated the energy stored by such pre-loaded springs or similar pre-loaded devices. Each exemplary embodiment of the ignition apparatus disclosed herein requires a predefined minimum acceleration to start the ignition sequence (or ignition train) and then a predefined sustained acceleration over time to generate the kinetic energy required to maintain the ignition sequence. If either the predefined minimum acceleration or the predefined sustained acceleration does not occur, then the ignition sequence (or ignition train) is not initiated. Projectiles having an ignition apparatus as disclosed herein may be safely stored indefinitely without the possibility of premature initiation of the ignition sequence.

The foregoing description of illustrated exemplary embodiments of the subject disclosure, including what is described in the Abstract, is not intended to be exhaustive or to limit the disclosed embodiments to the precise forms disclosed. While specific embodiments and examples are described herein for illustrative purposes, various modifications are possible that are considered within the scope of such embodiments and examples, as those skilled in the relevant art can recognize. In this regard, while the disclosed subject matter has been described in connection with various embodiments and corresponding Figures, where applicable, it is to be understood that other similar embodiments can be used or modifications and additions can be made to the described embodiments for performing the same, similar, alternative or substitute function of the disclosed subject matter without deviating therefrom. Therefore, the disclosed subject matter should not be limited to any single embodiment described herein, but rather should be construed in breadth and scope in accordance with the appended claims below.

What is claimed is:

1. An ignition apparatus for initiating an ignition sequence in a projectile, comprising:

a housing including an interior and a rear central opening in communication with the interior;

a sleeve being positioned within the interior of the housing and having a predetermined length, wherein the sleeve includes an interior space, a front end having a front opening and a rear end having a rear opening, wherein the front opening and rear opening are in communication with the interior space, and wherein the rear opening of the sleeve is aligned with the rear central opening of the housing;

a fracturable constraint device being positioned within the interior of the housing and adjacent to the rear central opening, wherein the fracturable constraint device includes a front side that is in abutting relation with the rear end of the sleeve and a rear side that faces the rear central opening, and wherein the fracturable constraint device is configured to fracture when subjected to a predefined magnitude of force caused by axial acceleration of the projectile;

a cap being attached to the housing and positioned within the rear central opening, wherein the cap abuts the rear side of the fracturable constraint device such that the fracturable constraint device is maintained in abutting relation with the rear end of the sleeve;

a firing pin being positioned within the interior space of the sleeve and configured to have high-density so as to provide high inertial mass, wherein the firing pin is secured to the fracturable constraint device;

a percussion primer being positioned within the interior space of the sleeve and spaced apart from the firing pin, wherein the fracturable constraint device is configured to fracture upon being subjected to the predefined magnitude of force thereby setting free the firing pin such that the firing pin does not accelerate with the projectile and is free to move within the interior space of the sleeve, and

wherein sustained axial acceleration of the projectile, the predetermined length of the sleeve and the high density portion of the firing pin are configured to cooperate and enable the firing pin to impact with the percussion primer with a force that is sufficient to activate the percussion primer.

2. The ignition apparatus according to claim **1**, wherein the sleeve includes an internal structure, which separates the interior space into a first interior space and a second interior space, wherein the internal structure includes an opening therein such that the first interior space is in communication with the second interior space, wherein the firing pin is located within the first interior space and the percussion primer is located within the second interior space, and wherein the firing pin includes a portion that is sized to fit through the opening in the internal structure so as to physical impact the percussion primer.

3. The ignition apparatus according to claim **2**, wherein the firing pin further comprises a forward portion that has a substantially conical shape, wherein the sleeve includes an interior surface extending about the first interior space, wherein the interior surface includes an interior portion that has a substantially conical shape that conforms to the conical shape of the forward portion of the firing pin.

4. The ignition apparatus according to claim **2**, wherein the firing pin further comprises a forward portion that has a substantially conical shape and which extends to a nose portion, and wherein the nose portion is a portion of the firing pin sized to fit through the opening in the internal structure configured to impact, physically, the percussion primer.

5. The ignition apparatus according to claim **1**, wherein the rear central opening of the housing includes a threaded surface, and the cap member has a threaded surface that engages the threaded surface of the rear central opening.

6. The ignition apparatus according to claim **1**, wherein the fracturable constraint device is fabricated from a material chosen from the group consisting of Polyether Ether Ketone and Acrylic Resin.

7. The ignition apparatus according to claim **1**, wherein the fracturable constraint device further comprises a protruding portion that outwardly extends from the front side of the fracturable constraint device, wherein the firing pin is secured to the protruding portion, and wherein the protruding portion is configured to fracture when the predefined magnitude of force is a predefined magnitude of tensile force.

8. The ignition apparatus according to claim **7**, wherein the firing pin includes a bore therein sized to receive the protruding portion.

9. The ignition apparatus according to claim **7**, wherein the firing pin includes a bore therein sized to receive the protruding portion, wherein the bore includes an inner surface, and wherein the protruding portion is adhered to the inner surface.

10. The ignition apparatus according to claim **1**, wherein the fracturable constraint device further comprises a central portion and a protruding member extending outwardly from the central portion, wherein the protruding member includes a head portion secured to the central portion and a threaded elongated portion attached to the head portion, wherein the firing pin includes a threaded bore and the threaded elongated portion is threadedly engaged with the threaded bore, and wherein the head portion of the protruding member shears off of the central portion when the predefined magnitude of force is a predetermined magnitude of shear force.

11. The ignition apparatus according to claim **10**, wherein the protruding member comprises a bolt, which comprises the head portion and the elongated threaded portion.

12. The ignition apparatus according to claim **10**, wherein the protruding member comprises a bolt, which comprises the head portion and the elongated threaded portion, and wherein the bolt is fabricated from metal.

13. The ignition apparatus according to claim **1**, wherein the firing pin comprises a section fabricated from high-density material.

14. The ignition apparatus according to claim **13**, wherein the high-density material is a high density Tungsten material.

15. The ignition apparatus according to claim **1**, wherein the firing pin comprises a generally cylindrical section and a high-density member, which attached to the generally cylindrical section.

16. The apparatus according to claim **15**, wherein the high-density member is generally cylindrically shaped and is attached to the generally cylindrical section of the firing pin such that the high-density member extends about the generally cylindrical section of the firing pin.

17. The ignition apparatus according to claim **15**, wherein the high-density member is fabricated from Tungsten.

18. The ignition apparatus according to claim **1**, further comprising generally cylindrical solid propellant member being positioned within the interior of the housing and extending about the sleeve.

19. The ignition apparatus according to claim **18**, further comprising:

a combustion chamber comprising an interior being in communication with the front opening in the front end of the sleeve, wherein at least a portion of the generally cylindrical solid propellant member is exposed to the interior of the combustion chamber; and

energetic material being disposed within the interior of the combustion chamber,

wherein activation of the percussion member is configured to cause combustion of the energetic material disposed within the combustion chamber, which in turn is configured to cause combustion of the generally cylindrical propellant member.

20. The ignition apparatus according to claim **19**, further comprising a nozzle cap enveloping the combustion chamber and having at least one exhaust port for exhausting combustion products within the combustion chamber.

* * * * *